Emerging transport solutions and their contributions towards sustainable rural transport systems

Inauguraldissertation
der Philosophisch-naturwissenschaftlichen Fakultät
der Universität Bern

vorgelegt von

Sebastian Imhof

von Riehen, BS & Göschenen, UR

LeiterInnen der Arbeit:

Prof. Dr. Heike Mayer
Geographisches Institut, Universität Bern

Prof. Dr. Widar von Arx
Institut für Tourismus und Mobilität, Hochschule Luzern

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Der Dekan
Prof. Dr. Zoltan Balogh

EMERGING TRANSPORT SOLUTIONS AND THEIR CONTRIBUTIONS TOWARDS SUSTAINABLE RURAL TRANSPORT SYSTEMS

Sebastian Imhof

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Three intensive years of research led to this thesis on rural mobility. Writing a thesis is always a collective effort and this one involved many people. I'm grateful for everybody who supported me in this time of highs and lows. Here, I'd like to address a few of them personally.

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ABSTRACT

Access to public transport in rural areas is important for preventing social exclusion and ensuring high quality of life. In contrast to urban areas, public transport provision in rural areas faces the challenges of more dispersed settlements and lower demand for services. Transport solutions such as demand responsive transport and ridesharing services may help to overcome these challenges and contribute to more sustainable rural transport systems. Even when many of these emerging transport solutions are meant to improve the entire transport system, each new service always has to be understood in its spatial context. Examples of ridehailing services, such as provided by Uber and DiDi Chuxing, proved to increase the flexibility of urban transport systems and render the ownership of a personal car superfluous. However, these services had negative consequences for taxi and public transport ridership, challenging long-established and historically developed transport regimes.

Although research on emerging transport solutions and their impact on transport systems has mainly been conducted in urban areas and in the context of smart cities, knowledge of how to implement suitable emerging transport solutions in rural areas remains insufficient. To better understand the conditions under which emerging transport solutions can help to solve the challenges of rural public transport systems, this thesis examines three transport solutions at various stages of their market presence and innovation: autonomous vehicles, demand responsive transport, and ridesharing. With the help of the literature on socio-technical transitions, this research seeks to better understand the potentials of these emerging transport solutions for more sustainable rural transport systems despite the challenges that the services face. The challenges discussed in this thesis are particularly related to the regulatory constraints and uncertainties these services face today and are expected to face in the future.

The findings show that each of the three transport solutions examined here is embedded differently in a transition towards a more sustainable rural transport system. This is related to the different impacts of each solution on rural transport systems. The introduction of autonomous vehicles to a rural public transport system has the potential to transform the entire regime. The findings show that the most positive transition would be achieved by combining autonomous vehicles with current railway services. The example of a rural ridesharing service, Taxito, proves to be guided by societal rather than economic goals. Its service design determines its position as a niche innovation that is only possible to provide within an existing car regime. The final innovation is a rural demand responsive transport system called mybuxi; this is also considered a niche innovation today due to the lack of regulations that might enable it to be part of the rural public transport system. Despite their

various positions in the transition towards a more sustainable transport system, all three transport solutions contribute to preventing the social exclusion of the most vulnerable individuals, such as elderly people.

All the emerging transport solutions examined here can help to improve rural accessibility. Moreover, they can contribute to the attractiveness of rural areas. A transition towards more sustainable rural transport systems may therefore provide added value.

KURZZUSAMMENFASSUNG

Der Zugang zu öffentlichem Verkehr im ländlichen Raum ist wichtig, um einen sozialen Ausschluss zu verhindern und um eine hohe Lebensqualität sicherstellen zu können. Im Gegensatz zu städtischen Gebieten steht die Dienstleistungserbringung des öffentlichen Verkehrs im ländlichen Raum vor der Herausforderung dispers besiedelter Siedlungsstrukturen und tieferer Nachfrage nach diesen Dienstleistungen. Transportlösungen wie nachfrageorientierter Verkehr und Mitfahrgelegenheiten könnten dabei hilfreich sein, diese Herausforderungen zu bewältigen und einen Beitrag zu nachhaltigeren ländlichen Transportsystemen zu leisten. Obwohl viele dieser neuen Transportlösungen das gesamte Transportsystem verbessern könnten, muss jede neue Dienstleistung im jeweiligen räumlichen Kontext betrachtet werden. Beispiele von Fahrdiensten, wie sie Uber und DiDiChuxing anbieten, zeigten, dass sie die Flexibilität urbaner Transportsystem erhöhen und den privaten Fahrzeugbesitz überflüssig machen können. Jedoch hatten diese Dienstleistungen negative Folgen für das Fahrgastaufkommen von Taxi-Dienstleistungen sowie des öffentlichen Verkehrs, was eine Herausforderung etablierter und historisch gewachsener Transportregimes bedeutet.

Obwohl die Forschung über neue Transportlösungen und deren Einfluss auf Transportsysteme vor allem in städtischen Gebieten und im Kontext von *Smart Cities* durchgeführt wurde, ist das Wissen darüber, wie neue Transportlösungen erfolgreich in ländlichen Gebieten implementiert werden können, bislang ungenügend. Um besser zu verstehen, unter welchen Bedingungen neue Transportlösungen einen Beitrag zur Lösung der Herausforderungen ländlicher Transportsystem leisten können, untersucht diese Thesis drei Transportlösungen in unterschiedlichen Stadien ihrer Marktpräsenz und Innovation: autonome Fahrzeuge, nachfrageorientierter Verkehr und Mitfahrgelegenheiten. Mit Hilfe der Literatur über sozio-technische Transitionen erstrebt diese Thesis die Potentiale neuer Transportlösungen für nachhaltigere ländliche Transportsysteme zu verstehen. Dies trotz den Herausforderungen, welche sich den Dienstleistungen stellen. Die Herausforderungen, die sich in dieser Thesis im speziellen stellen, sind mit regulatorischen Einschränkungen und Ungewissheiten verbunden, welchen sich diese Dienstleistungen bereits heute und vermutlich auch in Zukunft stellen müssen.

Die Ergebnisse zeigen, dass jede der drei hier untersuchten Transportlösungen unterschiedlich in die Transition in Richtung nachhaltigeren ländlichen Transportsysteme eingebettet ist. Dies steht im Zusammenhang mit unterschiedlichen Einflüssen jeder Lösung auf ländliche Transportsysteme. Die Einführung autonomer Fahrzeuge hat das Potential, das gesamte Regime zu transformieren. Die Resultate zeigen, dass die grösste positive Transition erreicht werden könnte, wenn autonome Fahrzeuge mit heute bestehenden

Zugdienstleistungen verbunden werden. Das Beispiel ländlicher Mitfahrgelegenheiten zeigt am Beispiel von Taxito, dass diese Dienstleistung vornehmlich soziale und weniger ökonomische Ziele verfolgt. Die entsprechende Ausgestaltung der Dienstleistung ist als Nischeninnovation positioniert, welche nur im Zusammenspiel mit einem existierenden Automobilregime anbietbar ist. Die letzte Innovation ist ein ländliches nachfrageorientiertes Transportsystem, genannt mybuxi. Diese Dienstleistung ist ebenfalls als Nischeninnovation zu bezeichnen. Aufgrund fehlender Regulatorien für solch ein System bleibt es der Dienstleistung verwehrt, als Teil des ländlichen öffentlichen Verkehrs anerkannt zu werden. Trotz ihrer unterschiedlichen Positionen in der Transition hin zu einem nachhaltigeren ländlichen Transportsystem tragen alle drei Transportlösungen dazu bei, sozialen Ausschluss der meistgefährdeten Individuen zu verhindern, wie beispielsweise von älteren Personen.

Alle hier untersuchten neuen Transportlösungen leisten einen Beitrag, die ländliche Erreichbarkeit zu erhöhen. Ausserdem sind sie wichtig für die Attraktivität ländlicher Gebiete. Eine Transition zu nachhaltigeren ländlichen Transportsystemen kann aus genannten Gründen deshalb einen Mehrwert mit sich bringen.

1. INTRODUCTION

Access to public transport (PT) in rural areas is crucial to preventing social exclusion, especially for elderly, younger, and disabled people (Shergold et al., 2012), and they are an important factor in ensuring high quality of life (Mounce et al., 2020). This thesis focuses on how emerging transport solutions are embedded in a transition towards more sustainable rural transport systems. New transport solutions face challenges that are in many cases related to the current predominance of existing PT services. Various pathways exist to challenge an incumbent PT system in rural areas in favor of a more sustainable transport solution. This thesis relies on the theory of socio-technical transitions (Geels, 2002, 2004, 2005, 2011) to help understand these processes.

Providing PT in rural areas differs strongly from urban areas, where an attractive combination of transport modes allows easy and fast access to transport services. More dispersed settlements in rural areas and longer distances between residential areas, working places, and services make the provision of attractive transport solutions more challenging than in urban areas. PT is less attractive than private transport because in sparse populated areas, the lower demand only allows low service frequency. This lower attractiveness leads to lower usage of PT services, which in turn makes the service provision cost-inefficient and leads to reliance on public subsidies (de Jong et al., 2011). This vicious circle has been described as the “rural mobility problem” (Mounce et al., 2020).

The emergence of new forms of mobility and the way these have been able to change transport provision was enabled by the increasing adoption of information and communication technologies (ICT) across the population (Alemi et al., 2019). In the past decade, new technologies and associated new forms of transport have emerged, entered, and in some cases disrupted the market for passenger transport; these include app-based ridesharing and ridehailing or demand responsive transport (DRT). The business model of Uber’s ridehailing service can be considered a disruptive pioneer. The emergence of this new form of mobility was associated with hopes that the entire transport and traffic system could be positively shaped in favor of increasing its sustainability by pooling trips, reducing traffic in cities, and reducing vehicle ownership (Circella & Alemi, 2018; Erhardt et al., 2019; Heilig et al., 2017; Meyer et al., 2017; Neoh et al., 2017). Contrasting findings show that ridehailing may increase congestion (Erhardt et al., 2019) and that PT ridership decreases where transport network companies provide their services (Kong et al., 2020). These negative consequences for the traffic system arise from the parallels between transport network companies’ services and existing PT services. Both services substitute each other, leading to competition between the two systems. This may ultimately result in an unsustainable traffic system (Kong et al., 2020).

The “rural mobility problem” (Mounce et al., 2020) and the possible negative consequences of new transport solutions in urban areas both indicate that emerging transport solutions implemented in rural areas should not compete with existing PT services. A popular emerging transport solution in rural areas in the past two decades has been the DRT services offered by dial-a-ride services. These services, mostly relying on volunteer drivers, are often restricted to certain community groups (Mulley & Nelson, 2009). Analyzing a rural DRT service in Germany, Sörensen et al. (2021) show that rural transport systems can profit sustainably from this transport solution if the service allows access to remote areas from one central stop such as a railway station. They further highlight that these DRT services should contribute to a reduction in rural car dependency. Ryley et al. (2014) indicate the importance of determining the institutional barriers that DRT services may face. In their view, overcoming these barriers contributes to effective DRT services that help to develop sustainable transport systems. Other transport solutions such as ridesharing services have also entered the rural transport market. Serving as a feeder system to other PT systems, ridesharing services enable better access to less populated areas by PT services (Stiglic et al., 2018).

All currently emerging transport solutions will be challenged by new technologies in the future. Here, the technology of autonomous vehicles (AV), especially when organized as shared autonomous vehicles (SAV), is considered to change the provision of PT services (e.g. Eppenberger & Richter, 2021; Haboucha et al., 2017; Hatzenbühler et al., 2021). (S)AVs can increase accessibility in rural areas by reducing costs and increasing the comfort of traveling and are likely to have consequences for, for instance, urban sprawl into these areas (Meyer et al., 2017). To prevent rural areas and the rural transport system from unwanted consequences, a better understanding is necessary of the challenges that emerging transport solutions face today. The papers presented later in this thesis highlight the regulatory challenges that emerging transport solutions may face as crucial for successful development.

Emerging transport solutions are embedded in a broader socio-technical system that consists of elements such as regulations and user practices that are reproduced and refined by various social groups (Geels, 2005). These systems consist of three interacting levels that may be described as a socio-technical landscape, dominant regimes, and niches. The mechanisms of interaction between these three levels are called a transition process and are represented in the multi-level perspective on socio-technical transitions (Geels, 2002, 2004, 2005, 2011). Innovations have a range of impacts on emerging transport solutions in rural areas and thus on the transition towards sustainable rural transport systems. Research so far has mainly focused on urban transition processes, so that little is known about the impact of emerging transport solutions in rural areas. Instead of competing with existing PT services, new transport services should contribute to more sustainable rural transport systems. The term *sustainable rural transport system* is here understood in rather broadly and depends on the spatial setting. Similar to Ryley et al. (2014), a sustainable rural transport system is understood throughout this thesis as an economically viable system which meets the social needs of the rural population and that is environmentally friendly. As will be shown in this thesis, the homogenous spatial settings of rural areas are crucial to various transition processes towards sustainable rural transport systems and calls for context-specific emerging transport solutions.

This thesis investigates three emerging transport solutions: shared autonomous vehicles (SAV), ridesharing, and demand responsive transport (DRT). It aims to uncover how they can contribute to the transition process towards functioning and more sustainable rural transport systems. It addresses a single overarching research question:

In which way do new transport solutions contribute to transition processes towards more sustainable transport systems in rural areas?

To address this research question, the thesis is organized into two main parts: first, a synopsis delineates the theoretical contextualization of the work, then a second part comprises three research papers. All three papers contribute to answering the research question, albeit each with a particular focus:

Paper 1: Shared Autonomous Vehicles in rural public transportation systems

Paper 2: Integration of ridesharing with public transport in rural Switzerland: Practice and outcomes

Paper 3: How social innovations emerge in a rigid regulatory context: The case of Demand Responsive Transport in Switzerland

The remainder of the thesis is organized as follows. Chapter 2 compares aspects of accessibility and indicators of mobility behavior in rural settings with those in urban and suburban contexts in Switzerland. Chapter 3 introduces the theoretical background to the research question of this thesis. Chapter 4 presents and reflects on the methodological approaches, and chapter 5 presents the conclusions of this thesis.

2. OVERVIEW ON ACCESSIBILITY AND INDICATORS OF MOBILITY BEHAVIOR IN SWITZERLAND

The term *rural areas* refers in this thesis to areas situated outside main metropolitan areas as described by Lagendijk & Lorentzen (2007), which is considered a functional definition (Gross-Fengels & Fromhold-Eisebith, 2018). Before this definition is used in the theoretical discussions within this thesis, a more structural definition of a spatial typology (Gross-Fengels & Fromhold-Eisebith, 2018) published by the Federal Statistical Office (FSO) is shortly presented as a helpful way to highlight spatial differences in accessibility and mobility behavior. In this typology, the FSO allocates Swiss municipalities to one of nine categories using a two-step procedure (FSO, 2017):

1. Urban-rural typology: Municipalities are first divided into one of the three categories of the definition of areas with urban characteristics. The categorization uses data on population density and commuter movements:

    a. Urban core areas (urban)
    b. Areas influenced by urban core areas (intermediary)
    c. Areas outside the influence of urban core areas (rural)

2. Municipality typology: Each of these three categories is divided into three subcategories, based on the population, number of employees, overnight stays in accommodation, area size, and accessibility of each municipality. The following nine categories are identified:

Urban	**Intermediary**	**Rural**
City with large agglomeration	Suburban municipality of high density	Suburban municipality of low density
City with mid-sized agglomeration	Suburban municipality of middle density	Rural, central municipality
City with small or outside of agglomeration	Central rural municipality[1]	Rural, peripheral municipality

Table 1 Municipality typology (9 categories)

Source: FSO (2017)

[1] Rural municipalities with central functions are allocated to “periurban municipalities”, whereas periurban municipalities with a low density are allocated to “rural municipalities”.

The typology presented in Table 1 allows sophisticated and differentiated discussion of the accessibility and indicators of mobility behavior. The papers presented after this synopsis investigate three regions with differing typologies and spatial characteristics, as shown in Table 2.

Paper	Region	Canton	Nr. of communes	Urban-rural typology	Municipality typology
1	Töss valley	Zurich	10	Intermediary (7)	Suburban municipality of middle density (7)
				Rural (3)	Suburban municipality of low density (2)
					Rural, central municipality (1)
2	Luthern valley	Lucerne & Bern	7	Intermediary (2)	Rural municipality with central functions (2)
				Rural (5)	Central rural municipality (5)
3	Ober-aargau	Bern	2	Intermediary (2)	Central rural municipality (2)

Table 2 Spatial typology, per paper

In brackets: number of municipalities per typology.

Source: FSO (2021b)

Table 2 clarifies that all three regions have different spatial characteristics. In particular, the regions of Paper 1, the Töss valley, and Paper 2, the Luthern valley, have very different characteristics. Most municipalities of the Töss valley are considered as areas influenced by urban core areas, whereas most of the municipalities of the Luthern valley are rural areas and therefore beyond the influence of urban core areas. The final paper is about two municipalities classified as intermediary in the urban-rural typology. At the same time, they are central rural municipalities in the municipality typology, highlighting their positions outside a metropolitan area (see Lagendijk & Lorentzen, 2007). These differences in the spatial settings of the regions are crucial because they determine the service design of emerging transport solutions.

2.1. ACCESSIBILITY

Emerging transport solutions may have varied impacts on overall accessibility in different spatial settings. Accessibility is here defined as “the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)” (Geurs & van Wee, 2004, p. 128).

A variety of authors agree that good accessibility is a crucial factor in maintaining or improving high economic competitiveness and social sustainability (e.g. Dugundji et al., 2011; El-Geneidy et al., 2016; González-González & Nogués, 2019). Tschopp and Axhausen (2016) also show that accessibility is an important factor in explaining population growth dynamics in a range of spatial settings. In rural areas, only municipalities that increase accessibility can attract new inhabitants and businesses. Accessibility in rural areas is therefore considered important to explaining population and economic growth. Theory agrees that easy accessibility of spaces and places especially prevents the social exclusion and marginalization of people reliant on PT solutions and who are not able to own or to drive a private car (Bromley et al., 2007; Nykiforuk et al., 2021; Vitale Brovarone, 2021; Vitale Brovarone & Cotella, 2020).

Accessibility and the negative consequences associated with low accessibility differ between urban and rural areas (Higgs & White, 1997). For example, better PT systems in high density areas can lead to lower car ownership, as time and place constraints are reduced by good access to PT (Oakil et al., 2016). Conversely, having no car in rural areas is considered a hindrance to fully participating in activities (Banister, 2008a; Kamruzzaman & Hine, 2011) because distances between services and opportunities are much higher than in urban contexts (Vitale Brovarone, 2021). To prevent social groups in rural areas from social exclusion, various aspects of accessibility need to be tackled with integrated policies (Vitale Brovarone, 2021; Vitale Brovarone & Cotella, 2020). Figure 1 shows the difference in accessibility of selected services in various Swiss spatial settings for the year 2015.

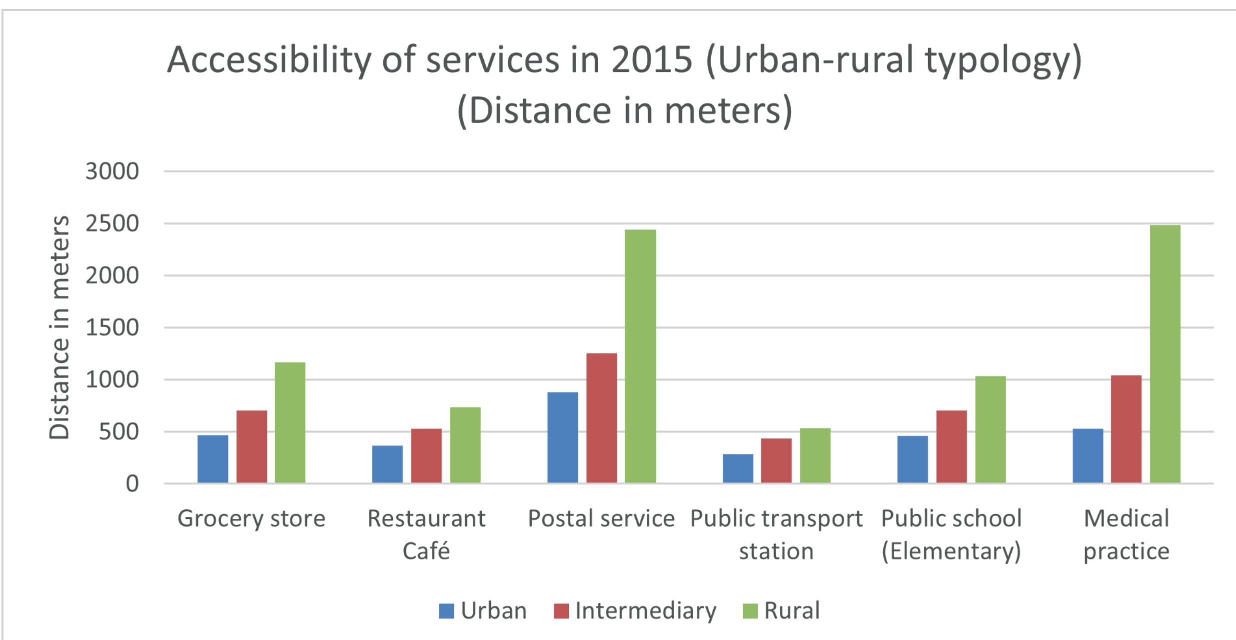

Figure 1 Accessibility of services in 2015, by urban-rural typology
Source: FSO (2018)

Services in urban areas are accessible at shorter distances than those in rural areas (Figure 1). Among the selected examples, although all show lower accessibility in rural areas than urban ones, postal services and medical practices stand out as particularly extreme examples. The differences in accessibility to PT stations between rural and urban areas appear less obvious. This observation is because here only the physical location of PT stations was measured. To uncover the true accessibility values for PT stations, the difference between all three types in frequency of services at these stations must be factored in and reflected in the "quality classes of public transport" (translated from the German *ÖV-Güteklassen*) (FOSD, 2021).

All three transport solutions examined in chapters 7 to 9 were shown to increase local accessibility, albeit with different consequences (Meyer et al., 2017; Sörensen et al., 2021; Stiglic et al., 2018). Current knowledge about SAV services (Paper 1) where PT services are limited today indicates that an increase in accessibility and consequent urban sprawl in rural areas can be expected to follow the introduction of the service (Meyer et al., 2017). Ridesharing services (Paper 2) appear to particularly enhance accessibility to services and housing along the first or last kilometer of a PT trip (Stiglic et al., 2018), in turn making PT more attractive for the rural population. Finally, in the case of DRT services (Paper 3), Sörensen et al. (2021) highlight that the increase in accessibility associated with new DRT solutions may also contribute to decreasing personal car usage.

2.2. MOBILITY TOOLS AND DAILY DISTANCE TRAVELLED IN DIFFERENT SPATIAL SETTINGS

The availability of a mobility tool is considered a good indicator for which forms of mobility people mainly use. The ownership of one specific mobility tool positively influences its usage and negatively influences the usage of any other mobility tool (Simma & Axhausen, 2003). For example, a higher rate of car ownership is a good indicator of lower usage of PT services (e.g. Goodwin, 1993; Holmgren, 2007, 2020). Scott and Axhausen (2006) reverse this relation and show that higher ownership of seasonal tickets for PT correlates with lower car ownership.

Spatial setting	**Availability of a car [%]**	**Ownership of driving license [%]**	**Ownership of PT season tickets [%]**
Total (Switzerland)	75.83	81.59	56.71
Urban	71.69	78.89	61.48
Intermediary	82.34	86.46	50.94
Rural	82.35	85.82	45.11

Table 3 Availability of mobility tools by spatial setting.

Source: FSO & FOSD (2017)

In Swiss rural and suburban areas, the availability of cars and the ownership of driving licenses are higher than the Swiss average and higher than in urban core areas, as indicated in Table 3. This observation is congruent with the finding that living outside urban cores increases car ownership (Scott & Axhausen, 2006). The converse distribution is apparent in the ownership of PT season tickets, showing the highest ownership in urban areas and the lowest in rural ones. This indicates that the population in rural and suburban areas more often relies on a private car than on PT services.

The daily distance travelled is a further important indicator of the mobility behavior of rural population. Generally, a longer journey increases the probability of choosing a private car as transport mode (Ding et al., 2017). Moreover, research has shown that trip lengths are an outcome of the built environment and that locations with easy accessibility, higher density, and mixed uses lead to shorter journeys (Ewing & Cervero, 2001, 2010).

Spatial setting	Total [km]	Human powered traffic [km]	Motorized individual traffic [km]	Public transport [km]
Total (Switzerland)	36.83	2.8	24.35	8.99
Urban	34.01	2.99	20.56	9.9
Intermediary	40.79	2.52	30.02	7.23
Rural	42.67	2.46	31.72	7.77

Table 4 Daily distance travelled by spatial setting
Source: FSO & FOSD (2017)

Table 4 shows that the highest total daily distance travelled is observed in rural areas. Slow traffic is the most sustainable mode of transport, and the urban population travels longer distances by foot and bike than the suburban or the rural population; the same relation can be seen in the use of PT. In line with Ewing and Cervero (2001, 2010), the lower usage of PT in rural areas can be explained by the sparseness of the PT network and therefore comparatively low accessibility. In rural areas and in certain suburban areas, accessibility to PT is often limited to single bus services that connect municipalities with the subordinate mass transportation system, especially the railway system. The largest differences can be found in the distances travelled by motorized individual traffic, especially by car: both the rural and suburban populations travel around ten kilometers more per day than the urban population.

2.3. DECREASING CAR DEPENDENCY

New, emerging transport solutions seek to decrease car dependency. In all three papers of this thesis, the goal of providing sustainable and attractive alternatives to journeys in private cars is one of the dominant reasons for providing transport solutions. The research literature also helps to understand the conditions under which people are willing to replace car trips with alternatives.

In Western European countries such as Sweden and Britain, attempts have been made to control or even reduce car usage by promoting public transport and other sustainable transport modes (Black & Nijkamp, 2002; Davey, 2007; Geels et al., 2012). Research shows that soft measures such as using climate morality and health issues to promote sustainable transport modes are important factors in decreasing private car usage. However, rural residents in particular react less favorably to these soft measures (Andersson, 2020). Economic incentives have also proved less effective in replacing car usage by more sustainable mobility services. The reason appears to be that many new mobility services do not provide the same advantage that car users value the most (Sjöman et al., 2020). Car owners also tend to underestimate the costs of car ownership by around 50% (Andor et al., 2020). To achieve behavioral change from individual transport modes towards more sustainable ones (Steg, 2005; Steg & Gifford, 2005), new innovative mobility solutions have to provide comparable flexibility and availability (Ahern & Hine, 2012; Ward et al., 2013). This is also the case for all three transport solutions in this thesis, which attempt greater flexibility than traditional PT services.

3. TRANSITION TOWARDS SUSTAINABLE RURAL TRANSPORT SYSTEMS

The important differences in the rural, suburban, and urban mobility systems of Switzerland (see chapters 2.1 and 2.2), indicate a need to better understand why and how a transition towards more sustainable transport systems in rural areas is achievable. As each of the three papers in this thesis has different theoretical backgrounds, it is the goal of this chapter to broaden the theoretical perspective on the role of emerging transport solutions and their contributions towards sustainable rural transport systems.

3.1. SMART AND SUSTAINABLE RURAL DEVELOPMENT

Rural areas can be promising hot spots of place-specific specialization (Akgün et al., 2015). This specialization is dependent on an innovation- and creativity-friendly environment. This is consistent with the vision of a “Smart Countryside” approach that calls for place-based transport innovation. These innovations have to be adapted to the needs of the rural population, including older people, younger people, and businesses (Bosworth et al., 2020).

Research shows that rural development can profit from high-frequency PT services, which also increase accessibility. There is a positive impact on rural tourism, and the social exclusion of people without their own cars may be prevented (Šťastná & Vaishar, 2017). Farrington and Farrington (2005) consider accessibility by PT services to be an important planning tool for rural areas.

It is also important to highlight that rural areas cannot be considered as homogenous spatial constructs. Naldi et al. (2015) demonstrate a need to advance beyond a simple classification of rural areas and include various place-specific aspects in any analysis of the smart development of rural areas. They show that peripheral rural areas can overcome their remoteness by smart specialization processes such as developing a creative economy and constructing specialized links to urban areas and economies. Here, the research by Noack and Federwisch (2019) also shows the importance of such urban–rural linkages when developing and implementing social innovations in rural areas of Germany. Social innovations in rural areas are therefore considered one possibility to overcome rural–urban divisions. This aligns with the view of sustainable rural development. According to Marsden (2009), the promotion and enhancement of sustainable economic potentials in rural areas has to rely upon networks between urban and rural areas that are able to provide the frameworks necessary for new emerging niches in rural areas.

In the papers presented in this thesis, the needs of the rural population without access to private cars are particularly addressed by illustrating emerging transport solutions that fulfil the need for attractive, flexible transport provision in rural areas. All the transport forms introduced in the three papers allow easy access to transport services and seek to maintain or increase accessibility in rural areas. To have an impact on rural development, these emerging transport forms have to be adapted to the local conditions. In this, innovation-friendly environments in rural areas seem to be crucial.

3.2. SUSTAINABLE TRANSPORT SYSTEMS IN RURAL AREAS

Transport development can influence regional economic performance (Olsson, 2009). Improving transport and mobility infrastructure can have positive consequences for rural accessibility. At the same time, the transport sector is currently one of the main sectors responsible for greenhouse gas emissions (Banister, 2011). Moreover, rural PT is currently under economic pressure resulting from underutilization and high subsidies (Avermann & Schlüter, 2019; Jokinen, 2016).

New transport developments must therefore be sustainable alternatives to current solutions such as fossil-fueled propulsion technologies and mobility solutions that promote unreflecting usage. Sustainable mobility is a theoretical response to current ways of organizing mobility systems (Hodson et al., 2017). General indications how mobility planning and services could become more sustainable are described in the sustainable mobility paradigm introduced by Banister (2008b) through four policy measures:

- Ensuring the usage of the best available technology and giving decision makers in the transport industry priorities on which technology to favor
- Including external costs in the actual costs of travel by regulations and pricing, for example through higher fuel prices or road pricing
- Ensuring land-use developments support shorter travel distances to reduce trips and travel distances
- Targeting personal information so that it increases acceptability of sustainable mobility.

A change towards these principles can only be achieved by including a broad coalition of stakeholders. Another concept for analyzing the transition towards sustainable public transport systems is the Avoid-Shift-Improve approach (ASI) (Dalkmann et al., 2014). The approach assumes that three main factors influence greenhouse gas (GHG) emissions from mobility in cities: technology, behavior, and urban forms. The “avoid” strategies tackle the reduction of mobility by promoting dense urban forms and reducing unnecessary trips. Strategies for a “shift” try to increase PT usage and lower trips with high-carbon modes. And “improve” strategies advance transport-related technologies that reduce fossil fuel usage and increase the energy efficiency of vehicles (Nakamura & Hayashi, 2013; Wimbadi et al., 2021).

However, research on sustainable mobility and the ASI-approach has so far focused on transition processes in urban areas. Research has mainly examined smart urban mobility (Cohen-Blankshtain & Rotem-Mindali, 2016; Fonzone et al., 2018; Lyons, 2018; Nakamura & Hayashi, 2013; Wimbadi et al., 2021; Zawieska & Pieriegud, 2018), which is part of the smart city concept. The smart city emphasizes the use of ICT and innovation in a city to positively influence and plan economic, social, and environmental aspects of the city life by addressing challenges in six dimensions: the economy, governance, mobility, environment, living, and people (see Anthopoulos, 2017; Caragliu et al., 2011).

The papers presented in this thesis show new mobility solutions developed in rural areas that try to contribute to this shift towards sustainable rural transport systems. Consequently, the question arises how the concept of the smart city and smart urban mobility may be transferred to rural areas. Unlike smart urban transport, literature on smart rural transport is scarce. Perhaps unsurprisingly, technologies and innovations evolving in smart cities, and especially the underlying algorithms, are aligned to urban problems and exhibit an urban bias. A direct transfer of new mobility solutions from urban areas to rural ones is difficult and currently insufficiently understood (Cowie et al., 2020). Gross-Fengels and Fromhold-Eisebith (2018) therefore call for rural-specific innovations in the mobility sector that are sustainable to contribute to economic revitalization and social coherence. Bosworth et al. (2020) use the concept of a “Smart Countryside” to highlight the need for place-based approaches when implementing mobility innovations in rural areas. In their view, change towards a smart countryside depends on the technological and socio-political infrastructure available in different rural areas and on whether innovators see the potential to involve rural areas in their networks.

3. 2. 1. MULTI-LEVEL PERSPECTIVE ON SOCIO-TECHNICAL SYSTEMS

The implementation of emerging transport solutions is embedded in a complex system of socio-political constraints and opportunities and a competitive environment between existing and emerging technologies. The introduction of the multi-level perspective on socio-technical systems proposed by Geels (2002, 2004, 2005, 2011) allows to better understand how new technologies can challenge, co-exist with or over time replace existing technologies.

> «Socio-technical systems consist of a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks [and] are actively created, (re)produced and refined by several social groups, for instance, firms, universities and knowledge institutes, public authorities, public interest groups and users.» (Geels, 2005, p. 446)

The multi-level perspective on a transition in socio-technical system is heuristically based on three levels of analytical concepts (see Figure 2): the socio-technical landscape (macro level), socio-technical regimes (meso level) and niche innovations (micro level) (Geels, 2002; Rip & Kemp, 1998). This hierarchical perspective allows the stability and dynamics of socio-technical systems to be understood.

The socio-technical landscape is defined as the broader contextual development on which actors of a regime have no influence and which influences the level of the socio-technical regime. A landscape is subject to slow-changing trends, such as demographics and ideology, and exogenous trends such as health and economic crises (Geels et al., 2017; Lopolito et al., 2011). At the meso level of the socio-technical regime, dominant technologies are key to a stable configuration of institutions, governance approaches, and regulations. The stability of the regime is ensured by incremental innovations (Geels & Schot, 2007; Lopolito et al., 2011; Smith et al., 2005). The dominance of a technology leads to a reinforcing cycle of high usage and diffusion of the technology in a society and consequent decreasing production and usage costs (Klitkou et al., 2015). The predominant structures of a regime are rather uniform across various contexts. But varying national, regional, and local contexts can lead to certain adaptations of a regime structure (Fuenfschilling & Binz, 2018). To change current practices in a dominant regime is difficult as there is a strong political and institutional support for the business-as-usual approach (Marsden & McDonald, 2019).

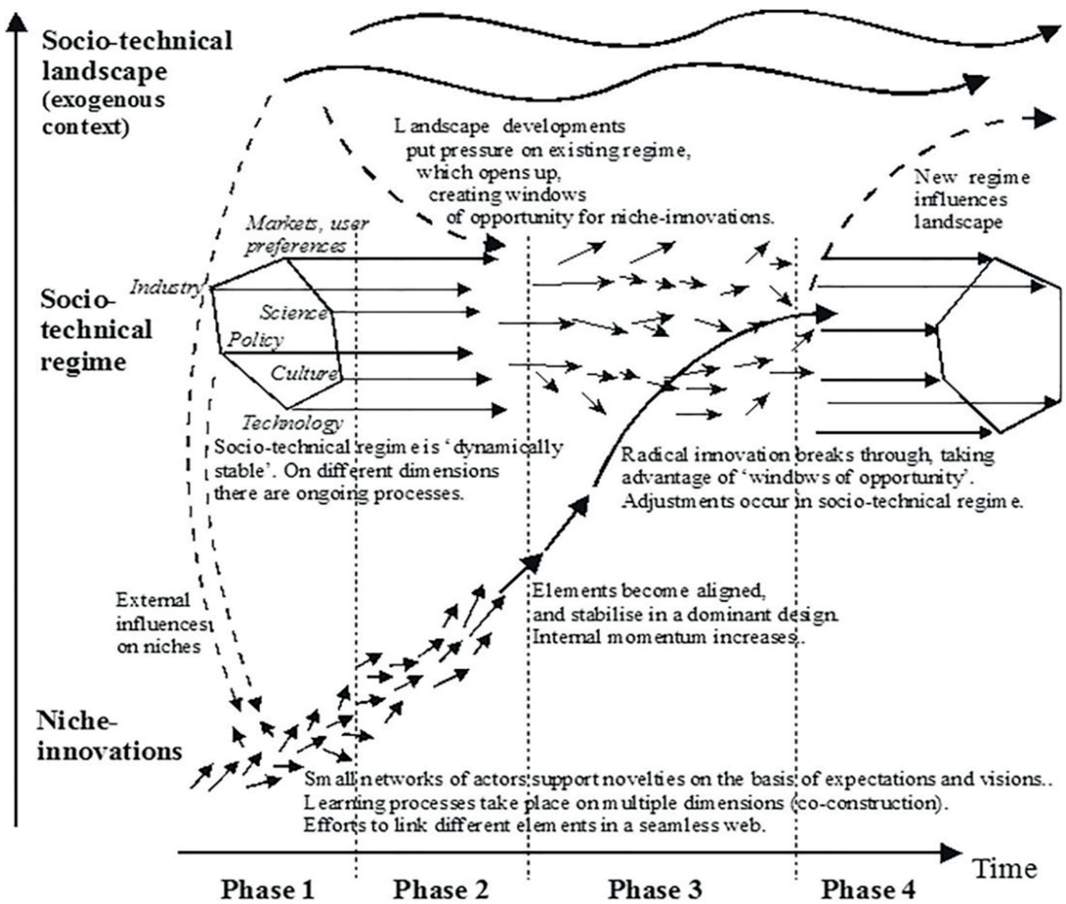

Figure 2 Multi-level perspective on socio-technical transitions.

Source: Geels (2017)

The transport sector incorporates various regimes with differing characteristics and corresponding infrastructures that have developed over many decades. The dominant system is the car system; other regimes include transport modes such as trains, buses, and slow traffic such as cycling. The car reached predominance and almost completely penetrated the market due to lock-in (Frantzeskaki & Loorbach, 2010; Unruh, 2000) and path dependency mechanisms (Åhman & Nilsson, 2008; Low & Astle, 2009). Urry (2008) highlights how the predominance of the car regime led to the externalization of dangers to people in traffic but not inside their own car.

This thesis examines the regime of PT services in rural areas. In rural Switzerland, the characteristics of these services are determined by a historically grown regulatory framework. A plethora of laws regulate PT. For instance, the minimal capacity for PT vehicles is defined as at least 9 seats per vehicle. Consequently, new services that try to provide a more flexible service with smaller vehicles cannot be accepted as PT. Not being accepted as a PT service implies that public subsidies are not available for the business. Conversely, PT services can be subsidized if costs remain uncovered. This situation then limits the economic viability of sustainable rural transport systems, and existing PT services can prove to be less effective and attractive than emerging transport solutions. At the same time, new mobility solutions face difficulties in fulfilling traditional funding criteria because the risk of failure is high, especially with pilot projects. Alternative funding sources have to be found, such as private and philanthropic funding (Grimm et al., 2013). The market entry of new transport solutions is further hindered by the protection of existing PT services: where PT services are provided under a concession, similar services are not allowed to operate.

3. 2. 2. TRANSITION FROM CLASSIC PUBLIC TRANSPORT TOWARDS SUSTAINABLE TRANSPORT IN RURAL AREAS

To systematically change a socio-technical regime, niche innovations can overcome lock-in mechanisms of the regime due to the radical nature of the innovation. Niche innovations at the macro level occur when alternative solutions are being developed in socio-technical configurations. In contrast to incremental innovations in a regime, niche innovations cannot rely on historically grown structures such as institutions and regulatory frameworks because they are radically new solutions (Fuenfschilling & Truffer, 2014).

A transition of the rural PT system which is currently mainly based on classical line-bound bus services towards a smart and sustainable transport system relying on sustainable, emerging technologies needs a transition at several levels of the multi-level perspective introduced in chapter 3.2.1. Although each transition is unique, Geels (2012) identifies three general dynamics that can trigger a transition:

- Niche innovations gain internal momentum and challenge the incumbent regime;
- a changing landscape puts pressure on the regime; and
- the destabilization of the regime, triggered by the two preceding processes, opens windows of opportunity for niche innovations.

A transition from one dominant regime to a new dominant regime can be a process of several decades or even centuries (Araújo, 2014; Fouquet, 2010; Geels, 2005). Examples of energy transitions illustrate the long-term shifting processes: from gas to electricity took approximately 125 years from invention to dominance, and from horses to railways took approximately 50 to 60 years (Araújo, 2014). Moreover, the dynamics of a transition are complex and not linear. They are an evolutionary result of interactions between such diverse dimensions as spatial arrangement, consumer behavior, and policy and actors such as consumers, industry, planners, and regulators (Geels, 2012). System failures in a socio-technical system are often met by specifically adopted institutional arrangements, technological infrastructure, and actor networks (Bos & Brown, 2012).

The transition from horse-drawn carriages to cars between1860 and 1930 illustrates how a transition has to be considered as a process embedded in a broad socio-technical context in which other regimes, in this instance electric tram systems, can co-exist and influence the transition (Geels, 2005). Thus, the mobility sector cannot be shaped or challenged by single emerging technological solutions (Schippl & Truffer, 2020), and especially in urban areas, a variety of sustainable mobility innovations compete, coexist, and complement each other (Hodson et al., 2017; Schwanen, 2015).

3. 2. 3. NICHE INNOVATIONS: SPACES FOR EXPERIMENTATION

Incumbent regimes are challenged by niche innovations, which may have a disruptive character. These niches are protected spaces in which new actor constellations try to develop an environment in favor of a new technology. Such niches can be considered as spaces for experimentation (Caniëls & Romijn, 2008). Experiments are driven by the long-term vision to contribute to the sustainability of socio-technical systems (Brown et al., 2003). Hodson et al. (2017) provide a framework on how a multiplicity of experiments contribute to a transition to urban sustainable mobility systems. Experiments interact with or challenge the incumbent system at three analytical levels. (1) Experiments can provoke a new equilibrium of new configurations with the existing system. (2) The governance of experiments may be in line with or in contrast with the governance approach of an incumbent system. And (3), understanding of the sustainability of a system and involved actors can be challenged by experiments.

Rooms for experimentation are often demonstration projects, as paper 3 of this thesis illustrates with the example of a rural DRT service. In experiments, the niche innovations are tested in real-life environments (Geels, 2012). These demonstration projects are especially important for developing knowledge about an innovation, from which regulatory instruments can be developed (Lo Schiavo et al., 2013). Experiments can also be considered a challenge for the state when there is an attempt to promote new sustainable innovations: changing or even replacing current governance approaches can be difficult to negotiate. The resulting governance approach will therefore bypass or dock onto existing policy regimes (Eadson, 2016).

Unlike in urban areas, multiple experiments do not emerge at the same time in rural areas because the financial and human resources are limited. Place-specific conditions are crucial to understanding how experiments and therefore niches can be implemented and sustained successfully. Understanding of the spatial embeddedness of transitions helps to better evaluate the potential of a transition towards sustainable rural transport systems.

3. 2. 4. SPATIAL EMBEDDEDNESS OF TRANSITION PROCESSES

In recent years, research on the spatial embeddedness of transitions has attracted increasing interest (e.g. Fromhold-Eisebith & Dewald, 2018; Murphy, 2015; Schippl & Truffer, 2020). Examining transitions involves embedding and examining the sociotechnical system in a territorial context of place-specific, multi-scalar relationships between actors, resources, and forces (Bauer & Fuenfschilling, 2019; Coenen et al., 2012; Raven et al., 2012). Raven et al. (2012) observe that spatial dimensions in transitions can be seen as relational products of actor networks between temporal settings with spatially heterogenous differences. This helps to understand spatial unevenness in transition dynamics (Murphy, 2015). Context-specific dynamics are important if innovators and decision makers want to avoid undesirable path-dependencies and rebound effects (Schippl & Truffer, 2020).

Hansen and Coenen (2015) summarize five place-specific factors to examine in transitions:

- Urban and regional visions and policies are important in the process of embedding and diffusing niche technologies.
- Informal institutions are adapted to local social practices.
- Local natural resources can determine how a region or a city invests in the development of renewable energies or technologies.
- Local specialization on specific industries and technologies can influence certain knowledge spillover effects on the development of an environmental-related innovation.
- Local consumers can be crucial for the creation of a market, especially where geographical proximity can enable close interactions between producers and consumers.

Different spatial settings set different conditions that determine how a region reacts to emerging technologies. In this thesis, the question arises how emerging transport solutions can successfully be implemented and diffused in different rural settings to contribute to transitions towards a smart rural transport future. For rural areas, the emergence of niche innovations can be considered a desirable policy aim, as they contribute to a revitalization of local economies and therefore to a general positive influence on rural development (Lopolito et al., 2011). Schippl and Truffer (2020) argue that a single focus on urban areas is insufficient when trying to achieve sustainable mobility systems. Moreover, urban-inspired visions on sustainability trajectories may even have negative consequences for rural areas due to their different settlement structures.

A new technology that is promoted due to its positive anticipated impact on the sustainability of a system may in the end only substitute a problematic situation with a new problem. Such circumstances can be called directionality failures, which result from diverging visions on a certain transition process and a lack of suitable regulations for the direction of change (Weber & Rohracher, 2012). To prevent such directionality failures, Schippl and Truffer (2020) show that spatial variety in urban and rural areas may lead to different alignments either inside or between sectoral regimes when implementing new technologies such as electric vehicles and automated driving. Data shows that the purchase rate of electric vehicles (EVs) is higher in small cities and rural areas than in metropolitan areas due to different circumstances (Frenzel et al., 2015). EVs therefore tend to stabilize the internal alignment of the rural car regime and continue to reinforce established directions. Conversely, EVs in urban areas weaken the car regime, as EVs are used increasingly for car-sharing systems. Car-sharing in urban areas that is based on EVs can contribute substantially to the goal of smart cities to have zero-emission mobility systems in inner city areas (Schippl & Truffer, 2020). Dang et al. (2021) also show that an increase of traffic volume related to on-demand mobility solutions has more negative impact on the urban traffic system than on the rural one. This agrees with Bosworth et al.'s (2020) call for mobility solutions that are adapted to rural needs. They emphasize that to attract social innovators, those responsible for rural transport must vocalize the social value of mobility.

3.3. EMERGING TRANSPORT SOLUTIONS IN SOCIO-TECHNICAL TRANSITIONS

Chapter 3.1 and 3.2 introduced the theoretical view of socio-technical processes. The next section summarizes transport and mobility solutions that may contribute to transitions towards more sustainable rural transport systems. Sprei (2018) identifies three major innovations that will disrupt mobility, despite the spatial setting: electrification, shared mobility, and automation. The combination of all three innovations will, according to Sprei (2018), have the largest potential for disruption.

3. 3. 1. SHARED MOBILITY

Shared mobility, understood as transportation services that are shared among users, include a variety of systems. The range includes the sharing of the same vehicle, such as car and bike sharing, to services where rides are shared such as traditional PT, taxi services, and individual ridesharing through car-pooling and ridehailing (Sprei, 2018). The spatial setting is important when examining these shared transport solutions. For example, Rotaris and Danielis (2018) highlight that the groups using carsharing differ depending on the spatial setting. If carsharing is offered in rural areas, students and unemployed people use the service frequently, whereas in urban areas professionals are the main users of carsharing systems.

In the three papers of this thesis, two forms of shared mobility are presented: personal ride-sharing through carpooling (Paper 2) and professionally organized, demand responsive transport (DRT) that allows door-to-door trips (Papers 1 & 3).

Carpooling schemes such as Taxito, HitchHike, and BlaBlaCar allow private car journeys to be shared and thus increase the use of a private car (Hartl et al., 2020). Different schemes target different target groups. For example, BlaBlaCar is an attractive, low-budget alternative for trips between cities that is often used by younger highly educated people (Shaheen et al., 2017). In contrast, carpooling in rural areas, as provided by Taxito for example, can be especially attractive for elderly people without their own car (Hartl et al., 2020; Su & Bell, 2009). Carpooling services can help to fill gaps in PT provision in remote rural areas.

Rural DRT services are better documented than rural carpooling services in the research literature. Replacing a fixed PT service by an on-demand service in a rural setting can help to reduce the overall vehicle kilometers travelled as well as the operational costs (Coutinho et al., 2020). The lower costs of the services are related to smaller vehicle sizes and novel technological solutions that allow greater service flexibility (Teal & Becker, 2011). Building on the vibrant local communities in rural areas, many services are provided by voluntary organizations (Gray et al., 2006).

3. 3. 2. AUTOMATION

Paper 1 of this thesis mainly focuses on a rural PT system for shared autonomous vehicles. Automation in the mobility sector is strongly associated with the technological development of autonomous vehicles (AVs). AVs, also often named self-driving vehicles, steer themselves without the assistance of a human driver and will probably change the entire mobility system drastically by improving the traffic system and reducing accidents (e.g. Bansal & Kockelman, 2017; Fagnant & Kockelman, 2015). Various demonstration projects worldwide have tested different forms of AVs, such as autonomous buses in Bern, Sion, and Stockholm (see Hatzenbühler et al., 2021; Mahmoodi Nesheli et al., 2021; SDA, 2019) and autonomous private cars such as Google's Waymo in California (Goodall, 2021). Eppenberger and Richter (2021) call for a unified transport enterprise that combines PT and shared autonomous vehicles (SAV) services. In their view, SAVs in urban areas are complementary services to the existing PT and should be used to serve so-far underserved city districts.

Meyer et al. (2017) show that AVs may increase accessibility in rural areas, in contrast to urban areas, where the increase in accessibility through AVs is lower. When used as vehicles for PT system, AVs organized into fleets even have the potential to replace current traditional PT with buses. Hilgarter and Granig (2020) highlight that the rural population in their study showed a more positive opinion about AVs than urban residents.

Regulations will be necessary to constrain AVs where they challenge more sustainable transport modes such as tram and railway services (Meyer et al., 2016) and where AVs may induce urban sprawl in rural areas (Fagnant & Kockelman, 2015; Hörl et al., 2019; Meyer et al., 2017). The economic efficiency of AVs in PT systems will depend strongly on their final costs. Like EVs, which are currently more expensive than fossil fueled cars, the costs of AVs will drop with mass production and mass adoption. And if used in shared systems, the cost of shared AVs is estimated to be 3 to 10 times lower than that of privately owned cars (Arbib & Seba, 2017; Bösch et al., 2018; Webb et al., 2019). Replacing human bus drivers with technological systems is considered an important factor in reducing the overall system costs of current bus services (Quarles et al., 2020).

3. 3. 3. ELECTRIFICATION

Electrification of the rural transport system plays a secondary role in all three papers of this thesis. But both the SAVs in Paper 1 and the ridesharing service in Paper 3 use electric vehicle fleets. The literature on electrification of the mobility can here be classified into two main categories, which are both related to the literature on socio-technical transitions: first, the adoption of electric vehicles and second, the distribution of charging stations.

In Switzerland, the purchase rate of EVs increased over the last decades from around 200 electric vehicles in 2010 to nearly 20,000 electric vehicles in 2020 (FSO, 2021a). Frenzel et al. (2015) showed that the rural population is more likely to buy EVs than the urban population. One reason for high adoption rate is the desire to become more self-sufficient: rural residents can charge their EVs at home and thus avoid trips to gas stations (Kester et al., 2020).

As EVs allow home charging, the high availability private parking places in rural areas can explain lower distribution rates of charging stations. When charging stations are planned in rural areas, the position and the speed of charging must be linked to the purpose of the trip. Commuters can charge their cars at their workplaces during work if necessary, and tourists can charge their EVs overnight at the hotel. In such situations, long-term parking allows slow charging speeds. More crucial rural points are those where people park for short periods: fast-charging infrastructure at such locations is therefore important to attract EV users (Niels et al., 2019).

4. METHODOLOGY

In Swiss rural areas, a broad range of new mobility solutions have emerged in recent years. In all three papers in this thesis, a case study approach was chosen as suitable methodology. The methodology of case studies is therefore shortly discussed in this chapter. The chapter also reflects on the qualitative research of expert interviews, which was used in two of the three papers.

Additionally, the case study of the third paper examines the use of AVs for PT services. Here, a scenario analysis was used that helped to develop a range of business models for using autonomous vehicles in a rural PT system. The scenario analysis is reported in chapter 4.2.

4.1. CASE STUDY APPROACH

The case study approach is an appropriate research method for gaining real-life insights into new mobility solutions. Case study research contributes to understanding how and why a certain phenomenon results from a certain setting. By including contextual conditions, researchers gain valuable insights into the people involved in the problem examined (Baxter & Jack, 2015; Yin, 2014). Case studies are ideal for examining emerging transport forms as the method allows researchers to understand how the transport services are situated in their organizational and geographical contexts.

All three papers used single case studies. In paper 1, a region was chosen as case study because of the availability of open data. In this paper, another research direction was chosen as the implementation of an AV fleet in a PT system is not possible. Consequently, the data available was used to conduct a simulation approach with a range of scenarios.

In paper 2, the ridesharing system of Taxito in the Luthern Valley of the canton of Lucerne and Bern was selected because Taxito was introduced in this region successfully. At the time the research was conducted, the service had already been established for some time. This helped to better understand the relationship of the Taxito service with the local PT system. The paper includes qualitative interviews and quantitative data on usage, but no statistical analysis was applied.

Paper 3 examined the case of mybuxi in the municipalities of Herzogenbuchsee and Niederönz. This case was ideal for understanding how the regulatory context of the PT regime shaped the planning process of an emerging transport solution. At the time of conducting the qualitative interviews, the planning process had finished a short while ago and was still in the recent memory of all interview partners. Other DRT services have been tested in Switzerland, but the mybuxi service is considered as unique. The mybuxi service can be classified as social innovation and is therefore unique in its provision of a PT-similar service. After the start of mybuxi in Herzogenbuchsee and Niederönz, it was introduced in two additional regions with different spatial settings.

The reproduction of the results of all three case studies in other regions will always need adaptation to the specific spatial contexts. Considerations here include the sizes of the area of operation, political contexts, socio-economic characteristics of the population, and the region-specific topography.

4.2. SCENARIO ANALYSIS (PAPER 1)

To examine how a regional PT system is impacted by AVs in rural areas, paper 1 identifies a range of anticipated scenarios. Scenarios help to deal with a high level of uncertainty of future development and generally contribute to the understanding of transition processes (see Shiftan et al., 2003; Swart et al., 2004; Wiek et al., 2006)

In paper 1, the starting points of the scenarios were the business figures of the current PT system. Thanks to the availability of open data, the current demand and supply of PT in the Töss Valley in the Canton of Zurich was chosen. The business figures on the supply side come from data on the operation of PT services. For the demand side, open data was provided by the Swiss government on the mobility behavior between all Swiss municipalities. Using data on these relations between municipalities simplified the research. This is because data on the door-to-door mobility behavior of the Swiss population is too complex to examine for a case study such as that in paper 1.

The scenarios in the paper were developed using elasticities for changing travel times and service intervals to estimate possible effects on demand. This calculated demand was used to generates data on the possible business figures of the use of AVs (Bösch et al., 2018). This data is always linked to a certain degree of uncertainty as the future use of AVs will differ from current knowledge of the technology, as Bösch et al. (2018) highlight.

4.3. QUALITATIVE RESEARCH: SEMI-STRUCTURED INTERVIEWS (PAPERS 2 AND 3)

For papers 2 and 3, case-specific qualitative research was conducted, mainly with the help of semi-structured interviews. The formulation of interview questions in a semi-structured interview is shaped by the research question which are collected in an interview guideline, also called a protocol. This guideline can be divided into several sections. Mostly, the interview begins with more general, narrative questions and becomes more abstract and theory-related toward the end of the interview. The semi-structured interview allows the researcher to exclude questions if the interview partner has already given the corresponding answer in the preceding questions. By doing so, the researcher can maintain an interesting conversation flow throughout the interview, concentrating on facts that have not been discussed so far. Toward the end of a semi-structured interview, time should always be allowed for the interview partner to discuss topics which were not addressed in the interview guideline but that relate to the research topic (Galletta, 2013).

The interview partners were selected due to their involvement in the mobility service examined. For paper 2, three interview partners were selected; in paper 3, 11 partners were interviewed. In both cases, the main actors were interviewed. The larger sample in paper 3 is related to the much higher complexity of planning for the mybuxi service in an uncertain regulatory environment. The smaller sample size in paper 2 is counterbalanced by the use of quantitative data on the usage of the Taxito system in the Luthern valley. In both cases, no user interviews were conducted due to the focus on the planning and implementation process.

Except one interview for paper 3, all interviews for paper 2 and 3 were conducted by telephone. Restrictions arising from the Covid-19 pandemic limited the possibilities for face-to-face interviews. Telephone interviews have the disadvantage that contextual and nonverbal data cannot be recorded by the researcher. However, the interview partners may feel more relaxed than when facing an unknown person (Novick, 2008). To maintain a comfortable ambience for the interview partners, all interviews were held in Swiss German. The interviews were all recorded with the same smartphone. Despite interruptions of the telephone connection in two interviews, no technical difficulties arose. In the interruptions, the interview partners repeated the last sentences they had spoken, and the interviews continued. In all interviews, the goal was to create an ambience that allows the interview partners to give detailed and unbiased answers to the questions.

All interviews were transcribed with F5 software. The language was translated from Swiss German to high German, always trying to maintain the original wording. For some Swiss German words, a translation is not possible. These words were not translated and were set in brackets in the transcript.

The analysis was case specific. For paper 2, a qualitative content analysis was conducted as proposed by Mayring (2010). For paper 3, the methodological approach of social innovation biographies was used (Butzin & Widmaier, 2016; Kleverbeck & Terstriep, 2017). Details on the methodologies used are described in both papers.

5. MAIN FINDINGS, CONCLUSIONS, AND OUTLOOK

This chapter presents the research goal and summarizes the main findings and conclusions of all three papers presented in this thesis. A synthetic overview of all the papers is provided in Table 5. Additionally, Figure 3 illustrates the anticipated overall socio-technical environment of sustainable rural transport systems, based on the findings of all three papers.

5.1. PAPER 1

SHARED AUTONOMOUS VEHICLES IN RURAL PUBLIC TRANSPORTATION SYSTEMS

The first paper (Imhof et al., 2020) examines the uncertain future of a fleet of shared autonomous vehicles (SAV) in a rural PT system. The case of the Tösstal valley in the Canton of Zurich is examined, thanks to the availability of open-source data. In line with the growing research literature on the use of SAV technology in PT systems, the paper proposes several transition pathways towards an economically sustainable rural PT system with a SAV fleet. Current uncertainties in the development of (S)AV technology in PT systems are addressed by introducing two scenarios with differing service designs. Compared to the current PT system, both scenarios introduce a door-to-door or door-to-station service. This service design covers the crucial first and last kilometers of trips and helps to increase rural accessibility. Both scenarios are compared with the current PT situation in the Tösstal valley. The scenario development also considers the literature of the regulatory framework of PT services in Switzerland. For each scenario, business figures are introduced and illustrated with geospatial analysis.

Comparing the business figures and the geospatial impact of the scenarios with the status quo provides helpful insights into the possible usage of SAVs in a future rural PT system. In scenario 1, all bus and railway services in the research area are completely replaced by a SAV fleet. As the SAVs allow more direct door-to-door trips than are currently possible with buses and trains, travel times are reduced, and the demand for PT increases. The cost-effectiveness of this scenario is found to be higher than both the status quo and scenario 2. However, the high demand for PT in this scenario results in more traffic on the roads. The geospatial analysis shows that scenario 1 may lead to a large increase in trips to a railway station outside the research area, which allows the fastest trips to the next urban core area. Scenario 2, in which a currently operating railway is kept operating, proved to have a lower impact on the overall traffic system than scenario 1. In scenario 2, a SAV fleet brings PT users to the railway stations situated inside the research area. Sustaining a railway line is more expensive than completely replacing the service with SAVs. These higher costs are balanced by a lower impact on traffic and on certain railway stations. The paper concludes that a rural PT system with SAVs should sustain current mass transport systems to limit the environmental impact of SAV fleets in a rural PT system. The regulator will have to actively coordinate a rural PT system in favor of well-balanced systems between a flexible SAV fleet, ensuring last-kilometer services, and a line-bound mass transport system that allows direct transport to central locations such as regional hubs and city centers. Here, the paper proposes that the current tendering system for single PT lines must be replaced by calls for tenders for entire regions. The paper illustrates that complete replacement of a current rural PT regime by an SAV fleet is not optimal. Combining the current PT system with the emergent (S)AV regime is optimal for an economic and ecological sustainable rural PT system.

5.2. PAPER 2

INTEGRATION OF RIDESHARING WITH PUBLIC TRANSPORT IN RURAL SWITZERLAND: PRACTICE AND OUTCOMES

The second paper (Thao et al., 2021) analyzes the Taxito ridesharing scheme in the Luthern valley, including areas of the Cantons of Lucerne and Bern. The goal of Taxito is to provide an additional transport mode for the population of rural areas where PT is scarce. Unlike the other two services, Taxito does not cover the first or last kilometer but ensures a constant transport service between scheduled PT services. The topography of the Luthern valley is typical for many mountainous regions in Switzerland. Points of interests in the region, such as a church of pilgrimage at the end of the Luthern valley, and settlements in general are more easily accessible thanks to Taxito.

The results of the paper show that the Taxito system can be well integrated into a rural PT system. The success of this integration is secured by participatory planning processes, the integration of Taxito notice boards in the local bus stops and railway stations, journey prices slightly above those of the bus services. The active collaboration between ridesharing and transport enterprises in planning and communicating a service such as Taxito helps to sustain such services despite low usage rates. The paper also illustrates successful interaction between the niche innovation of Taxito and the rural PT regime. However, the ridesharing service is reliant on the dominant car regime. Further research will be necessary to better understand which factors may increase the usage of rural ridesharing services.

5.3. PAPER 3

HOW SOCIAL INNOVATIONS EMERGE IN A RIGID REGULATORY CONTEXT: THE CASE OF DEMAND RESPONSIVE TRANSPORT IN SWITZERLAND

The third paper (Imhof & Mayer, submitted) examines the rural DRT system of mybuxi, a service introduced in 2019 in the municipalities of Herzogenbuchsee and Niederönz in the Canton of Bern. The goal of the social innovation of mybuxi is to improve accessibility to PT services with a door-to-door service. Here, one goal is to cover the first and last kilometers in the service area. By doing so, the system replaces trips with private cars. The service is provided with electric cars and volunteer drivers. This paper focuses on the interplay between the social innovation of mybuxi, which so far is a pilot project, with the regulatory framework of the PT regime. The literature on the social innovation process helps to better understand how regulatory questions shaped the planning process during the stages of innovation.

The findings of the paper show that the PT regime especially dominates the final planning stage of the social innovation. Here, the ambitions to become part of a rural PT system of the actors involved in the innovation process were not successful. The PT regime proved to be rigid and highly protected by the regulations, which have evolved over time. This circumstance implies that mybuxi does not qualify for public subsidies at this stage of the innovation and therefore has to find other ways to finance its service. These findings are helpful for planning emerging transport forms in the future. Knowledge of the rigid regulatory framework must be considered as soon as possible in an innovation process to avoid unanticipated impacts.

Research focus	Transport solution	Geographical scope
Paper 1: Imhof, S., Frölicher, J., & von Arx, W. (2020). Shared Autonomous Research in Transportation Economics, 100925.		
Discussion on the regulation of the usage of SAVs in a PT system in a Swiss rural context and scenario analysis of different business models	Autonomous vehicles	Tösstal valley, Population: ~ 35,000 people
Paper 2: Thao, V. T., Imhof, S., & von Arx, W. (2021). Integration of ridesharing Transportation Research interdisciplinary Perspectives, 10, 100340.		
Practice and outcomes of integrating ridesharing with PT in a rural context. Special attention to the ways in which key stakeholders cooperate with each other in designing and implementing the integration process.	Ridesharing: Taxito	Region of Willisau & Luthern Population: ~ 21,000 people
Paper 3: Imhof, S., & Mayer, H. (2021). How social innovations emerge in a rigid [Manuscript submitted for publication]		
The impact of uncertain regulatory framework on the planning process of an emerging transport solution in a rural context	DRT with electric vehicle: mybuxi	Municipalities of Herzogenbuchsee & Niederönz Population: ~ 9,000 people

Table 5 Overview of the three papers of this thesis

Own illustration

Methodological approach	Main findings
Vehicles in rural public transportation systems.	
Case study: Scenario analysis	When developing new rural PT systems with emerging AVs, future regulations have to incorporate combining line-bound mass transportation (e.g. railways) and flexible AV service. A combination of the incumbent traditional rural PT regime of buses and railways and the emerging AV regime is optimal for an economic and ecological sustainable rural PT system.
with public transport in rural Switzerland: Practice and outcomes.	
Case study: Mixed-methods approach	A niche innovation such as Taxito can successfully be integrated with the help of participatory planning processes, the integration of Taxito notice boards in the local bus stops and railway stations, and journey prices slightly above those of the bus services. The niche strengthens the rural PT regime but is reliant on the dominant car regime.
regulatory context: The case of Demand Responsive Transport in Switzerland.	
Case study: Social Innovation Biographies	Planning a niche (social) innovation such as mybuxi can face regulatory constraints linked to the dominant regulations of the PT system especially in the late planning stage. The rigid regulatory framework of the PT system influences funding schemes and service designs.

5.4. DISCUSSION AND CONCLUSIONS

Tackling the “rural mobility problem” (Mounce et al., 2020), this thesis provides insights into improving rural transport systems by incorporating or substituting existing PT services with emerging transport solutions. Differences detected between indicators of mobility behavior in rural, suburban, and urban populations in Switzerland underpin current research on the possible transition towards sustainable rural transport systems. All three papers contribute substantially to understanding this transition process and presenting possible avenues to reaching sustainable rural transport services, either in the PT regime or outside the regime as a niche innovation. Each service examined is currently in a different stage of innovation, but all contribute to answer this thesis’s research question:

In which way do new transport solutions contribute to transition processes towards more sustainable transport systems in rural areas?

The attempt of all three transport solutions to increase the attractiveness of rural transport systems may contribute to decreasing private car usage. They also illustrate varied approaches in which the first and last kilometers of trips without a private car in rural areas may be provided with alternative and sustainable transport solutions. Increasing the accessibility of formerly underserved rural areas generally helps to increase their attractiveness (Farrington & Farrington, 2005) and may even contribute to shifts towards non-car transport modes (Oakil et al., 2016). All three innovations contribute to rural transport systems in which certain subpopulations, especially elderly and younger people, have good access to sustainable transport solutions without being reliant on their own cars or on family and friends (Bosworth et al., 2020). These subpopulations would otherwise be socially excluded (Bromley et al., 2007; Nykiforuk et al., 2021) as they have suffered the most from the reduction of PT lines in cost-efficiency optimization attempts in the established PT regime following the loss or reduction of state subsidies.

Using the multi-level perspective on socio-technical transitions proposed by Geels (2002, 2004, 2005, 2011), this thesis shows that all three transport solutions investigated contribute differently to the transition process towards sustainable rural transport systems. All anticipated and possible transition processes of the three transport solutions are illustrated in Figure 3. A complete replacement of an incumbent regime is possible with the emergence of SAVs (see Nr. 1 in Figure 3). On current knowledge, SAVs may help to increase PT ridership in rural areas because trips can be provided door-to-door or at least door-to-station. This stands in contrast to urban areas, where SAVs may either complement or compete with current PT services (Eppenberger & Richter, 2021), as the urban PT system already provides fast, high-frequency, attractive, and sustainable trips for the urban population today.

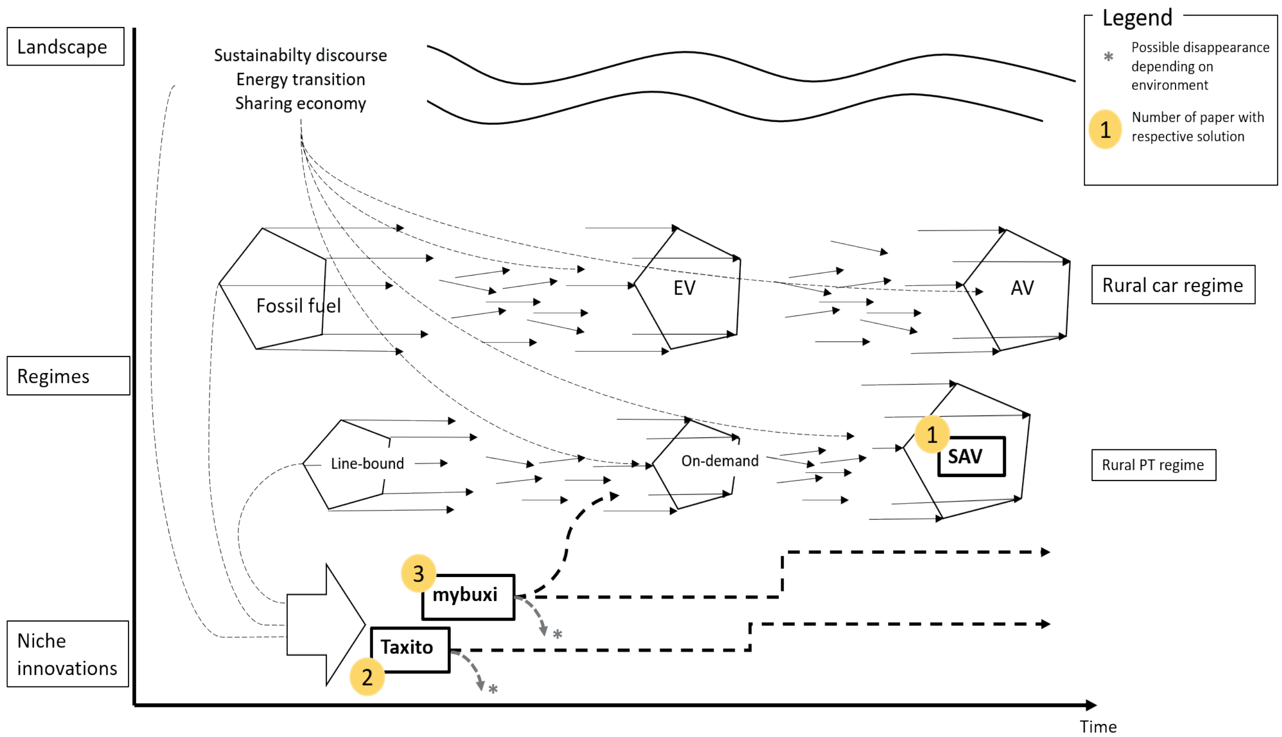

Figure 3 Socio-technical environment of a sustainable rural transport system
Own illustration, inspired by Geels (2017)

Taxito's ridesharing service pursues another goal than replacing an entire PT regime. Clearly conceived as a niche service, Taxito depends on the incumbent private car regime and acts as a complement to the rural PT system (see Nr. 2 in Figure 3). The niche here helps to provide a low-threshold service for those members of a rural population that do not have access to a private car. Even though the Taxito service is being scaled up across new regions, the service may remain a niche. The service is particularly well adapted to especially remote rural areas, but it can only be successful in combination with a dominant car regime, making use of existing cars and their drivers to provide the service for Taxito users. The third innovation investigated, the mybuxi DRT illustrates the struggles and constraints of a niche innovation trying to be part of a rigid existing PT regime. Here, the incumbent PT system defines the regulatory framework and determines or even limits the opportunities for a rural DRT service. Becoming part of the PT system is not possible for mybuxi today. But experiments such as mybuxi provide valuable insights on the possibilities of emerging transport solutions in real-world settings (Geels, 2012). Even when challenging state governance approaches (Eadson, 2016), these experiments help to develop appropriate regulatory instruments (Lo Schiavo et al., 2013) for emerging transport solutions. On current knowledge, it remains unclear whether DRT services such as mybuxi may become part of the PT regime or may form a subregime in rural areas (see Nr. 3 in Figure 3). Future research will have to gain further insights into how the regulatory framework of the existing PT regime can and will be shaped in the future in favor of more flexible, attractive rural transport solutions. What is also important to highlight is that that these services, especially the niche innovations, may disappear over time, depending on other niches in the market or the increasing dominance of an incumbent regime (see Figure 3).

The literature on transition processes also calls for context- and place-specific views on local transition processes (Murphy, 2015). Here, local preconditions such as local consumers and local social practices have to be taken into account (Hansen & Coenen, 2015). All the scenarios presented for the SAVs in the PT system of the Töss valley are based on current demand for PT services. The willingness of the local population to adopt SAVs in their transport system will be crucial for the future success of services with the new technology. The region is diverse in its spatial conditions, as is highlighted in the different spatial typologies of the municipalities involved (see Table 2). Future research will be necessary to understand how these spatial differences help or hinder a transition towards sustainable PT systems with SAVs in a rural context.

The Taxito case in the Luthern valley is embedded in a peripheral rural region with dispersed settlements. The development of Taxito is directly linked to this spatial setting. Due to the low population density, current PT services are infrequent. By adding the possibility of obtaining a ride in between scheduled PT trips, Taxito contributes to increasing the overall frequency of local, sustainable transport solutions. This is especially helpful for people without access to a private car. Past experience shows that Taxito even strengthens PT services, preventing the cancellation of PT lines. At the same time, this service allows connections municipalities that were not connected with PT services before, increasing the regional accessibility. The low population density would also not allow a new service with employees or volunteers because low demand for such a service would have rather low cost-efficiency. A challenge faced by the service is its reliance on the willingness of local car drivers to pick people up. The service can also be considered as contributing to a more environmentally friendly rural transport system, as more car trips are shared. Future research will need to better understand the scaling possibilities of low-threshold innovations to provide these services successfully and sustainably in peripheral rural areas.

For mybuxi in Herzogenbuchsee and Niederönz, the spatial preconditions led to a completely different transport solution that was suitable for the local population. Both municipalities are comparatively densely populated for rural areas and are situated closely around a single train station. Short distances to and from the train station allows a DRT service to be efficient, as does a certain degree of pooling of passengers in single trips. The large number of volunteer drivers that provide the mybuxi service is a crucial factor in providing a sustainable transport solution. This willingness to be part of a sustainable transport solution without monetary compensation is crucial for the success and the financial viability of mybuxi and highlights the importance of local social practices. Such practices must be taken into account when devising and implementing transitions towards sustainable rural transport systems (Hansen & Coenen, 2015). And, as mybuxi currently provides several DRT services in different spatial settings with similar service designs, comparative analysis of the spatial conditions for success and failure of rural DRTs using mybuxi can and should be pursued. Knowing more about the relation of the mybuxi service with the spatial conditions encountered may help scale up the service. The motivation of volunteer drivers in such transport solutions should also be investigated in more detail in the future because their involvement could positively impact the attractiveness of certain transport solutions in their rural settings.

The literature on socio-technical transition processes also helps to understand the current and future challenges that these transport solutions may face. The mybuxi DRT solution

(Paper 3) and the anticipated emergence of SAVs in a PT system (Paper 1) both highlight the importance of understanding the regulatory framework under which a service is allowed to operate. Current regulations tend to help protect incumbent regimes. This is currently the case in Switzerland for the PT and private car regimes. Emerging transport solutions must either adapt these regulations or try to challenge them. The case of mybuxi showed that challenging current regulations in favor of a sustainable rural transport solution is a long process that also depends on the willingness of the regulator to adapt some regulations. The process to be acknowledged as PT service is also related to many uncertainties, as the adaptations depends on the individuals within the authorities responsible for these decisions. However, SAVs are expected to incrementally replace PT services using vehicles with drivers regardless of whether these are line-bound or on-demand services. The regulators will have to consider both the positive and negative consequences of innovations on rural PT systems to contribute to a sustainable rural transport future. Thus, the following policy recommendation seems to be appropriate. Regulators must be willing to support transport solutions that have already proved or are expected to improve rural transport systems. Long and complex decision-making processes hinder innovation in rural areas, as these limit the flexibility and creativity of new and existing transport providers. If some services prove to have a positive impact on the sustainability of rural transport systems, regulations should be adapted in favor of the more sustainable transport solution.

The emergence of novel transport solutions in rural areas has increased over the last decade as new services proved themselves to be attractive to the rural population, overcoming an urban bias about transport solutions. When PT services are subject to shortages of public subsidies, these emerging solutions can establish in niches, filling gaps left by the reduction of services or even the cancellation of PT lines. Furthermore, some emerging transport solutions have been shown to improve rural accessibility over incumbent PT services and contribute to the overall attractiveness of rural areas. Side-effects of novel forms of transportation may include such effects as improving social inclusion and reducing the ecological footprint of rural inhabitant. The transition towards more sustainable transport systems therefore does not need to come at a cost or disadvantage and may even prove to offer added value.

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SHARED AUTONOMOUS VEHICLES IN RURAL PUBLIC TRANSPORTATION SYSTEMS

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Shared Autonomous Vehicles in rural public transportation systems

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ABSTRACT

This article focuses on the economic potential and the consequences on the regulatory context of Shared Autonomous Vehicles (SAV) used in a regional public transportation system. Based on an experimental case study two on-demand scenarios were developed for the Swiss rural area of the Töss Valley. Scenario 1 replaces the current public transportation by SAVs; scenario 2 operates with a SAV fleet instead of buses and integrates the regional railway. Data sources are an overall traffic model and the current business figures of the public transportation. The results suggest that scenario 2 is, out of an economic and traffic system view, an attractive solution compared to line-bound traditional bus and train systems. In both scenarios, a cost-covering service may be possible due to an increase in productivity and demand. Regarding the present regulatory context of the Swiss public transportation system, we propose to change the system of call for tenders for single public transportation lines towards a call for tender for entire regions. This paper contributes to the scholarship discussion on the role of the final provider of new services and which adaptions of current regulations have to be targeted in the future.

1. Introduction

Autonomous vehicles may help to reduce traffic congestion as well as accidents and may influence travel behaviour (Fagnant & Kockelman, 2015). Fully autonomous vehicles (level 5[1] after the taxonomy of: SAE, 2016) are expected to be cheaper (Bösch, Ciari, & Axhausen, 2016) and more sustainable (Brown, Gonder, & Repac, 2014, pp. 137–153) than traditional transportation modes. At the same time, the increase in comfort and the possibility to use the travel time as productive time could inverse the positive aspects of the autonomous vehicles into negative effects: the higher comfort may lead to an increase in the vehicle usage and the vehicle kilometres travelled (Fagnant & Kockelman, 2015). Those different views on possible impacts of autonomous vehicles show that transportation planning should take into consideration different scenarios of the usage of autonomous vehicles in order to provide a sustainable public and private transportation system in the future.

According to the authors' reading of literature, studies on the implementation of autonomous vehicles in the public and private transportation system show a high concentration on urban areas (e.g. Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2015; ITF, 2015; Spieser et al., 2014) and are often calculated on agent-based simulations (e.g. Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2015; Heilig, Hilgert, Mallig, Kagerbauer, & Vortisch, 2017; Hörl, 2017; Hyland & Mahmassani, 2018). At the same time, a study conducted by Meyer, Becker, Bösch, and Axhausen (2017) predicts that rural public transportation can profit more from Shared Autonomous Vehicles (SAV) than urban areas. The reason can be found in the high public transportation coverage in urban areas whereas in rural areas public transportation can only be provided on minimal scale due to low population density and low demand. At the moment, there is a difference in the reliance and the attitude of the population in urban and rural areas regarding the public transportation system (Gray, Farrington, & Kagermeier, 2008, pp. 102–119).

During the last few years, new on-demand mobility services based on smart-phone apps like Uber, DidiChuxing or Lime experienced a rapid growth. However, ridehailing services were implemented faster than the regulator could respond to the market entry. In order to protect the local

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[1] Definition of level 5 of driving automation: "The sustained and unconditional (i.e., not ODD-specific [operational design domain]) performance by an ADS [automated driving system] of the entire DDT [dynamic driving task] and DDT fallback without any expectation that a user will respond to a request to intervene." (SAE, 2016).

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taxi market, some regulators prohibited the provision of ridehailing services, whereas in other regions their market entry was facilitated. The regulation of ridehailing services shows that the entry of new players in the mobility sector can depend on the regulators' view on the implications of a new service on the entire transportation system (Deighton-Smith, 2018). For instance, a study conducted by Hörl, Becker, Dubernet, and Axhausen (2019) in an urban context shows the importance in regulating the usage of privately owned autonomous vehicles as they could lead to an increase of 40% in the total vehicle kilometres travelled. Another scenario with the service provision by autonomous and pooled taxis shows in lower increase of 25% in the total vehicle kilometres travelled.

In this current paper, we will concentrate on the discussion on the regulation of the usage of SAVs in a public transportation system in the rural context of the Töss Valley region in Switzerland. We will present the current regulatory context and then make first predictions on how the regulation of different SAV scenarios could look like in the future. The paper will focus on a public transportation system in a Swiss rural area. By defining two different scenarios of changes in the public transportation system with the entry of autonomous vehicles, we simulate the possible effects of an on-demand and door-to-door SAV service on the public transportation system in the research perimeter of the Töss Valley. Assessing the different possible scenarios then helps to discuss the regulatory context of the proposed services. The authors want to open up the discussion on how the regulator may react on the usage of SAVs in the public transportation system, operating on-demand. Different from many agent-based simulations, we focus on the overall system of the public transportation.

The remainder of this paper is organized as follows: Section 2 introduces the current regulation context of the public transportation in Switzerland. Section 3 discusses the research context, the methods of the simulation as well as the assumptions behind the two scenarios. The results are presented in Section 4, followed by the discussion for future implications of the regulatory context of SAV services in the public transportation system in Section 5.

2. Regulation in the current Swiss public transportation

In order to understand different SAV services in public transportation and their regulatory needs, the present context of regulations in public transportation in Switzerland will be presented hereafter (BAV, 2019).

The Swiss public transportation system is divided in four subsystems:

- Long-distance traffic
- Regional traffic
- Local traffic
- Touristic traffic

All those subsystems pursue different goals and are regulated in different ways. Our simulation of new SAV scenarios concentrated on the context of the regional public transportation, therefore the regulatory context will focus on this subsystem.

2.1. Regulation of the regional public transportation

The Swiss law describes regional public transportation as the transportation provided by buses or trains within and between adjoining regions as well as the rough allotment of local communities. Two conditions have to be fulfilled for declaring a line to be part of the regional public transportation. First, bus or rail lines need to make local communities with more than hundred inhabitants accessible. Second, there has to be at least at one end of the line a connection to the superordinate public transportation system, and they have to make at least one local community accessible. If a line fulfils these conditions, the Swiss Confederation as well as the cantons order the line and subsidize uncovered costs (BAV, 2019). The subsidisation of the public transportation is considered as a public service (UVEK, 2016).

In order to provide the most cost-efficient service, there is a process of tender offers. The invitation for tenders is necessary, if

a) there is a new line for the regional public transportation planned and a concession is necessary. If the anticipated uncovered costs of the line are under CHF 230,000 per year, there is no need for the tender offer process.
b) a concession is renewed and the canton has defined in the first tendering process that the line has to be put out for tender again after the concession has expired.
c) the transportation provider was not able to fulfil the predefined obligations during the concession.

If a new line is planned to become part of an existing regional network of public transportation lines provided by the same operator, the process of the tender offers is not necessary. The reason behind this exclusion is, that matching the new line with the existing lines can increase the synergy potential of the transportation provider (BAV, 2019).

New lines are put out for tender if the regulator sees uncovered demand in a region, but further needs of different stakeholders must be considered in the assignment process of each service too:

- the service has to provide an adequate basis exploitation of the area;
- the service is a request of the regional politic, especially for fulfilling the needs of economic development of peripheral and mountainous regions;
- the service has to be conform with the land use planning;
- the service has to be conform with environmental protection;
- the service has to consider the needs of handicapped persons (Schweizerische Eidgenossenschaft, 2010).

There is the possibility of objections, if one of the listed stakeholder's needs is not considered in the planning of the new line service. Therefore, the most relevant stakeholders in this case are representatives and politicians of peripheral/mountainous regions, land use planner, environmental activists and handicapped persons.

By winning the tendering, the transport operator has to fulfil several obligations on the provided transportation lines, the most important obligations include:

- Paying customers must be transported (transport obligatory).
- The transport operator is obligated to provide timetables for the lines and to provide the service during the defined operation hours.
- The transport operator defines tariffs for the transportation service, which are adjusted to the frequency, the quality and the cost of the service.
- Services in the regional public transportation system must be integrated in the subordinate public transportation system. There are subordinate tariff systems that have to be adopted and tickets have to be provided over the boundaries of their own service area (BAV, 2019).

2.2. Summary of the present regulatory situation

New lines in the Regional Public Transportation are generally given to operators that can fulfil the different criteria described above. Each line is granted a single concession in order to bundle all the demand on one provider of a line. If there would be no monopoly in the line, the competition may lead to lower cost-efficiencies and higher substitutes that are necessary. Currently, there are 114 transportation operators providing 1425 lines in the Swiss regional public transportation system. The Swiss Confederation subsidies them annually with around one billion Swiss francs (BAV, 2019).

3. Empirical context

3.1. Research perimeter

The Töss Valley is located in the upper-east of Switzerland (see Fig. 1) and is the study site of this current study. The research area consists of ten villages with around 35,000 inhabitants in total (Federal Statistical Office, 2018). The passenger railway line S26 is crossing the whole region and the research area. The entire area is located in the canton of Zurich, the most populated Swiss canton. We chose the Töss Valley because of its location and availability of high quality traffic data and business figures of current public transportation. The valley is located southeast of and close to Winterthur, Switzerland's sixth biggest city and a second-tier city. Winterthur attracts most outbound trips with public transportation from the research area, followed by Zurich, the biggest city in Switzerland. Today, the trip to Winterthur from remote villages takes around 30–45 min, and the trip to Zurich takes 45–55 min. From villages near the S-train S26, the trip with the railway takes between 13 and 36 min, and around 45 min to Zurich.

3.2. Status quo and two SAV scenarios

The current public transportation system (see Fig. 1), here called status quo, builds upon two main transportation modes. First, the S-train S26 traverses the research area of the Töss Valley, starting from Winterthur in the north. In the south, the S-train is separating in the south side of the perimeter in two lines. The S-train S26 operates two times an hour: to the half hour only until the end and to the full hour further south of the research perimeter. The second main transportation mode are several fixed route bus lines operating to and from the S-train stations of the S26 line. Several of the bus lines operate between the S-train stations of the S26 and the S3 south of the research perimeter; additionally, numerous short bus lines connect settlements and municipalities with the S-train stations. Depending on the line, the buses operate mostly hourly or each half hour. The overall traffic model indicates around 8800 person trips with public transportation on an average weekday in and out of the research area. One transportation enterprise provides the entire regional public transportation system, the "Zürcher Verkehrsverbund" (ZVV). The motorized individual transportation, in contrast, generates nearly 82,000 trips on an average during weekday, showing that there is a lower demand for public transportation in the research area, valued from the Swiss perspective.

Scenario 1 (see Fig. 1) builds on the entire replacement of the public transportation inside the research area by a SAV fleet, which means no bus or S-train operates anymore. Two different trip modes are possible in this concept. First, all trips to other villages inside the research perimeter are provided by door-to-door SAV trips. Second, for trips outside the research area, SAVs transport the users from their home to an S-train-hub outside the research area. In this scenario, the S-train S26 does not operate inside the research area anymore but operates autonomously between the hub "Sennhof-Kyburg" and Winterthur as well as from "Steg" to the south.

Scenario 2 (see Fig. 1) combines the SAV service with the existing S-train S26 line passing through the research area. Therefore, we only substitute the current bus system by on-demand SAVs. The train operates autonomous in this concept, too. Seven existing train stations along the S26 supplement the hub concept. The two sorts of trips in scenario 1 are complemented by two additional possibilities of transportation. First, SAVs bring users from their home to a train station where they change to the S-train. Second, users living near the train station are able to walk to the station and then take the S-train. We assumed a walking distance of 5 min as reasonable.

3.3. Data sources and assumptions

For realistic estimations of the business figures of both new

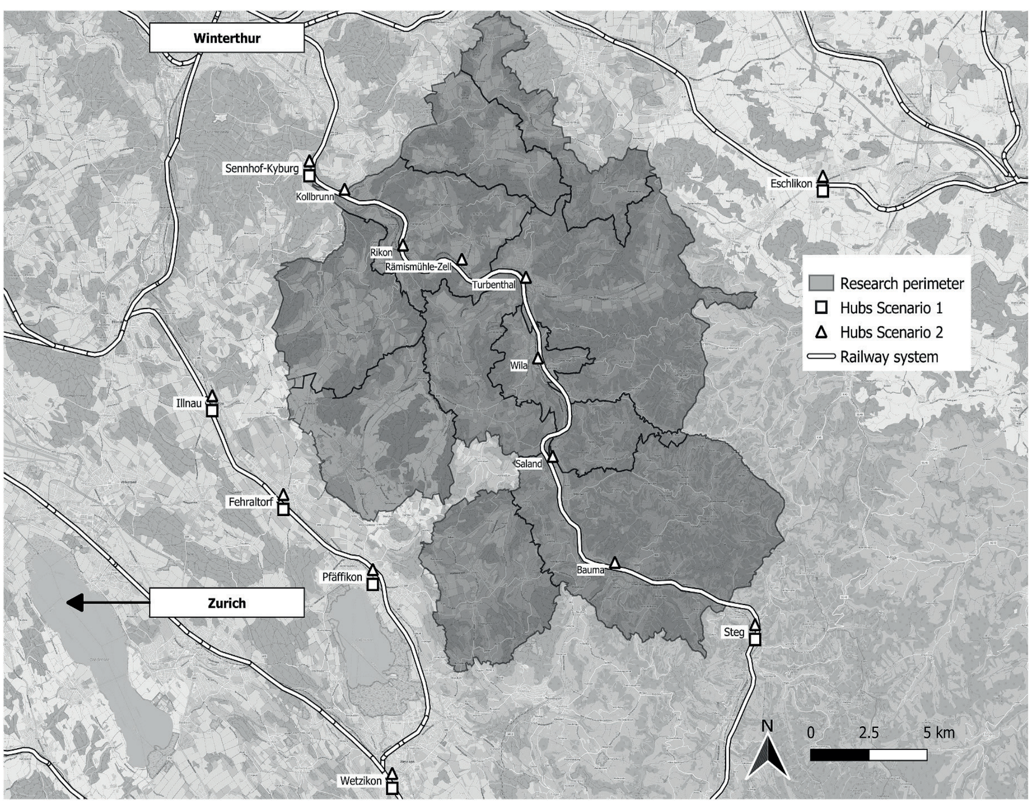

Fig. 1. Empirical context and scenario 1 and 2.

scenarios, we used and analyzed two main data sets. First, the overall traffic model of the canton of Zurich was source of the top ten origin-destination-relations for each village in the research area. This means, that either the origin or the destination, or both, of a trip is registered in one of the ten villages in the research area. The relations are then aggregated on the level of the village, where we always used the village center for further analysis. The overall traffic model (Volkswirtschaftsdirektion Kanton Zürich, 2011) focuses on passenger traffic inside the canton of Zurich as well as the connections from and to the neighbouring cantons. The model differentiates between motorized individual and public transportation traffic as well as human powered (by foot and bike) mobility. Included are all traffic networks, being for public transportation the stops, points of transportation mode changes, hours of service and intervals of each line. The data is available for an average working day as well as for peak hours in the morning and in the evening and for the traffic between 11 and 12 o'clock. The origin-destination-relations are the base of estimating the changes in demand due to improvements in travel time, interchanges of the transportation mode and changes in the interval frequency. Second data set are business figures of the current (situation 2013) railway and bus system for estimating the cost-efficiency of the new scenarios, based on the concept specific demand.

The research is based on data of the anticipated costs and revenue of SAVs and the change in demand due to changes in the travel time and the service interval. Bösch, Becker, Becker, and Axhausen (2018) show that the costs of a 8-seat SAV used in regional circumstances, similar to our research area, will be at 0.55 CHF per km per vehicle. The costs calculation of Bösch et al. (2018) include on one hand the variable costs like depreciation, cleaning costs of the vehicle and abrasion of the tires. On the other hand, fixed costs (e.g. insurance, tax and parking costs) of the vehicle are included as well. For the S-train, costs of 11.26 CHF per kilometre were calculated, based on the available data of the business figures of the current public transportation in the research area. The revenue side builds upon scientific data on the perceived costs of operating SAVs as well as own calculations on the ticket-based costs. Each public transportation user in both scenarios pays 1.70 CHF (based on own calculations that are based on the current public transportation system) as ticket base for the entire trip and 0.16 CHF per travelled kilometre, regardless of the transportation mode.

For the average degree of utilization of the SAVs with eight seats, Bösch et al. (2018) spatially differentiates between suburban and rural areas and temporally between off-peak and peak hours. Four of the villages in our research perimeter were classified as rural, six villages as suburban areas. For the suburban area, the degree of utilization during off-peak hours is assumed as 2.5, rising to 3 persons per trip during peak hour. In rural areas, the degree of utilization is lower with 1.5 persons per trip during off-peak hours and 2 persons per trip during peak-hour.

Further, the level of productivity of the SAVs must be included in the cost-efficiency analysis. During peak-hour, the SAVs can operate during 60 percent of the operation time with the transportation of guests. Distributed over the day the level is little lower at 50 percent. The productivity level results from the calculation of 100 percent minus the charging time, waiting time and transfer time (Bösch et al., 2016 in Bösch et al., 2018).

We used following elasticities (Vrtic & Fröhlich, 2006) to anticipate the change in demand:

- For change in the travel time an elasticity of 0.598
- For the service interval an elasticity of −0.191

The change in travel time was based on Google Maps trips, which was then compared to the current travel time of the bus and S-train services. For the service interval, we calculated an interval of 10 min for the SAVs, but the S-train remained on two services per hour. As this paper wants to open up the discussion the topic of regulating future SAV services, we forbear to go more into detail of the calculation steps of each key performance indicator presented in the results.

3.4. Limitations and discussion of the simulation

The estimations in this paper as well as in other studies on the impact of (S)AVs on the transport systems are based on numerous assumptions (Soteropoulos, Berger, & Ciari, 2019). In this paper, the estimations of the model-specific demand are built upon today's customer trips with public transport in the research area. It was not focus of the research to assess the possible shift away or towards the usage of privately owned vehicles.

The simulation is limited to current transport data and prospective usage scenarios for autonomous vehicles in public transport systems. All trip costs are based upon today's figures, broken down to the costs per kilometre. The different SAV scenarios will lead to different trip lengths for the same origin-destination relation: in scenario 1, trip routes are more direct than in scenario 2. Consequently, kilometrage, revenues and costs differ between the scenarios.

Further, both scenarios end at the research border or at hubs in neighbouring areas. The present study scenarios manipulated the public transport services originating or ending singly within the research area. Adjacent and connected public transport areas may influence the outcome in the study area, depending on their own usage of autonomous vehicles in public transport.

The chosen simulation can be considered as a new approach to test possible business models with real data on the current usage of public transport. We differ from frequently used agent-based models by focussing only on the available data and by looking more into business model aspects of replacing parts of the public transport offering with SAVs rather than the consequences of such a replacement on the entire traffic system from a transport planning standpoint.

4. Results and discussion

The different assumptions and consulted scientific cost-analysis lead to the following business figures.

4.1. Forecasts of the different scenarios

4.1.1. Change in demand

Both scenarios show (see Table 1) an increase in the total passenger trips. In the present system, there are nearly 2.9 million passenger trips with the bus. The passenger trips with the S-train are on 1.1 million. In scenario 1, we see an increase of the demand in the form of the passenger trips of around one million additional trips, for scenario 2 the passenger trips rise by 0.9 million.

The reason for the high increase in both concepts can be seen in the

Table 1
Annual business figures, per scenario.

Figures (annually)		Scenario		
		Status quo	1	2
Costs	in millions of CHF	16.22	11.80	14.00
Revenue		8.30	13.09	15.17
Gains		−7.9	1.28	1.17
Cost-efficiency		51%	111%	108%
Total Vehicle Kilometers Bus	in millions of km	1.18	–	–
Total Vehicle Kilometers SAV		–	16.39	9.73
Total Vehicle Kilometers S-train		0.68	0.21	0.77
Passenger trips (bus or SAV)	in millions of trips	2.90 (bus)	3.83 (SAV)	3.02 (SAV)
Passenger trips (S-train S26)		1.12	1.59	1.78
Trips by foot to railway S26		unknown	–	0.72
Total passenger trips		2.90	3.83	3.74

direct trips of the SAVs inside the research area as well to the hubs with a calculated changing time of only 5 min to the S-train. In addition, the trips include only maximum one changing process, reducing the overall travel time.

The increase in demand is higher in scenario 2 due to more direct trips especially to the hub "Sennhof-Kyburg" (see Fig. 1), where the most trips are leading to. They are more direct, as the SAVs operate mostly diagonal towards this hub; in scenario 2 the SAVs operate to the hubs inside the research area, leading to less direct trips compared to Scenario One and therefore to slightly longer trip lengths. The trips are less direct, as the SAV trip to the hubs lead to a slight detour compared to the diagonal trips toward "Sennhof-Kyburg".

4.1.2. Cost-efficiency

In the status quo, the entire system can only be provided due to subsidies, as only 51% of the revenues cover the costs. The estimations of the two scenarios show a high gain in efficiency of the entire system. In scenario 1, we see an increase of the gains per year. By replacing the entire public transportation system by SAV, this ratio jumps over the hurdle of 100%. The revenues are 11% higher than the total costs. The explanation behind this efficiency increase can be manifold. At first, the omission of the driver's task lowers the costs of the system. This is only possible when SAVs can drive without any driver being present in the vehicle, being the above-mentioned level 5. A further aspect of the increase in efficiency is the attractiveness of the door-to-door service. This can increase the demand for public transportation as well as the bundling effects. The demand is increasing due to lower travel time and direct trips without changes of the line or the vehicle.

Compared to scenario 1, scenario 2 shows still a higher revenue side than the system should cost, but it is with 108% slightly lower than seen in replacing the entire public transportation by SAVs. The usage of S-train in this system leads to the highest costs of all three scenarios. As the driver's task in trains is responsible for only about 15% of all the costs (bus: around 50%), the system sees slightly lower gains in the end. However, due to attractive direct trips towards the different S-train hubs, the system remains attractive and attracts more passengers than the current system.

4.1.3. Effects on the traffic situation

In the current system, buses in the research perimeter are responsible for 1.18 million vehicle kilometres travelled per year. In both new scenarios, we can see a high increase of the total vehicle kilometres travelled. In scenario 1, SAVs travel 16.39 million kilometres. This increase of the total vehicle kilometres travelled by a factor of nearly 14 compared to the current situation may put a high pressure on the entire road system within the research perimeter. By integrating the S-train in the system, the pressure can be lowered, nevertheless SAVs are still responsible for around 9.72 million vehicle kilometres in the research perimeter (factor of 8.2 more vehicle kilometres travelled compared to today).

Beside the overall increase of vehicle kilometres, it is important to consider local consequences on the traffic situation, too. We did that by assessing all trips to a hub in both scenarios for the peak-hour traffic. In Fig. 2, we depict the frequency of trips to and from each individual hub in both scenarios.

Due to the proximity of the Töss Valley to the city of Winterthur, most of the trips are going towards the north-west of the research perimeter. The hubs situated northeast, in Pfäffikon, Fehraltorf and Illnau, register a high number of trips, too, as the passengers have the possibility to change to the train in direction of Zurich. There are only few trips going north or south, due to less workplaces or points of interest in these regions.

In scenario 1, the placement of all hubs outside the research perimeter has the consequence, that the nearest hub to Winterthur, Sennhof-Kyburg, registers the highest frequency. This high frequency during peak-time may lead to congestion problems, as all SAVs are planned to

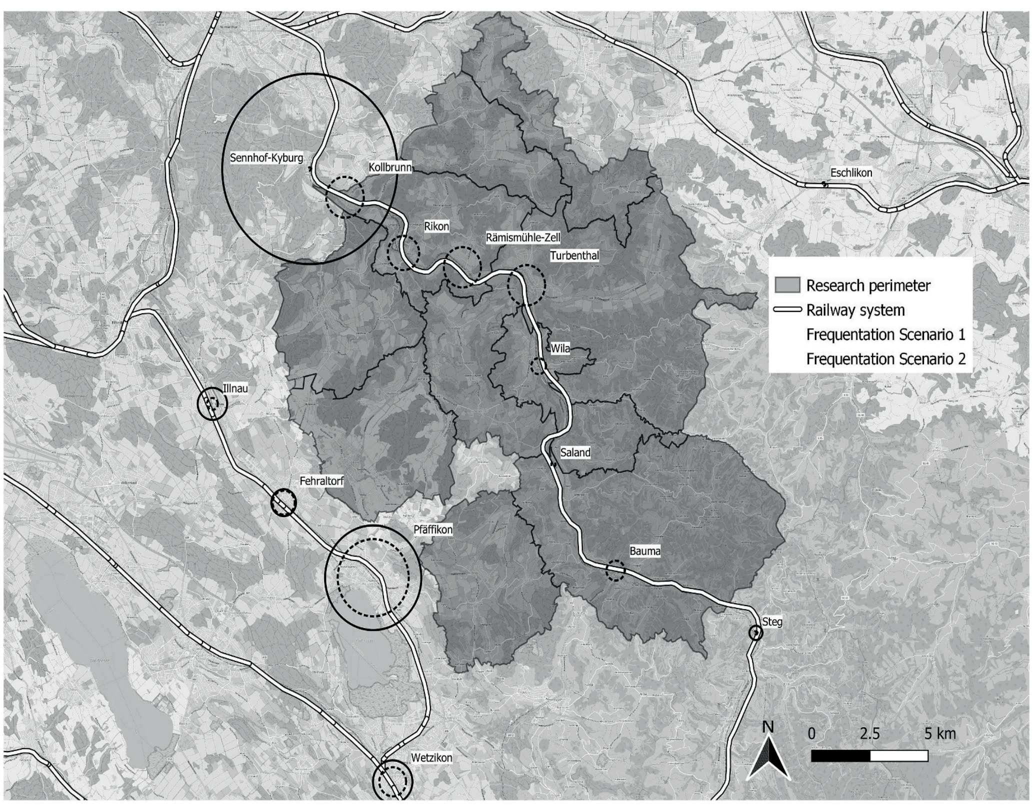

Fig. 2. Frequency of trips to and from each hub in scenario 1 and 2 during peak-hour.

arrive at the hub a short time before the departure of the S-train towards Winterthur. Two anticipated problems are overloads of the access roads to the hub station and parking problems at the station.

By re-integrating the S-train system in scenario 2 as well as respecting footpaths to the hub stations, this punctual congestion problem can be dissolved and distributed over the entire S-train-line. The hub with the highest frequency in scenario 2 can be found southwest of the research perimeter in Pfäffikon with the connection possibility towards Zurich.

5. Discussion on the regulatory needs in the future

In this current study, we attempted to develop two future scenarios of SAVs used in a regional public transportation system. By analysing their implications on the economic and traffic system, we anticipate that a system entirely built upon SAVs shows the best economic gains but has high implications on the traffic system. Impacts can be seen in a huge increase in the total vehicle kilometres travelled by the SAVs as well as punctual concentrations of traffic at single hubs. Consequences may be an overload of the entire road system and local congestion problems at the access roads to the hubs.

Scenario 2, combining the SAV service with the existing S-train line, showed lower gains than scenario 1 did, but there would be no subsidies needed as the system is self-feeding, too. In addition, having an S-train crossing through the research perimeter helps to reduce a certain number of trips with SAVs, to bundle demand in big vehicle sizes and to prevent the hubs from a high frequency during peak-hour. Even when the traffic impact is increasing in scenario 2 compared to the status quo, the local overload of a single hub are avoidable and the entire traffic system is less afflicted than in scenario 1.

We showed in Section 2 the present situation of the regulation of the regional public transportation. With our two scenarios, we tried to maintain the current level of service and the goal and condition of the public service in the research perimeter. Nevertheless, both scenarios would need adaptions of the regulatory context. Today, for every new single line in the Swiss regional public transportation, a call for tender is necessary. An exception of this principle is given when a line can be integrated in an existing network of public transportation lines provided by one enterprise (BAV, 2019). From our point of view, there are adaptions necessary to this regulation. First, the call for tender for single lines in a regional SAV service as presented in both scenarios would make no sense, as the service is not line-bound anymore. In contrast, the SAV service would be flexible and on demand, operating on order with direct trips to the hubs or to the destination inside the research area. We therefore propose to open the line-bound regulation towards a call for tender for entire regions, in which the SAVs have the allowance to operate freely. It would be necessary to specify the perimeter in detail and if there are areas, where the SAV cannot operate, for example in pedestrian zones.

The change from a line-bound to a highly flexible service would have further implications: an on-demand door-to-door service does not need any timetable anymore if the passengers can order their trips per app (or other technological solution). A possible service each 10 min like in our estimations seems to improve the accessibility enormously in a rural area, where currently buses operate sometimes only hourly or less frequently. However, in order to maintain the current service quality, there have to be some restrictions. Especially the connection guarantee at the hubs from one transportation mode to another has to be ensured in order to provide a fast, easy and comfortable service to the passengers. Here, the regulator has to provide standard guidelines for the transportation operators how the connection between transportation modes has to be organized. A door-to-door service has also implications on the access of different passengers, especially handicapped persons. The entrance and exit of a vehicle needs to be suitable for handicapped persons and there has to be enough space for wheelchairs and other aids. In our estimations, we excluded the needs of handicapped persons as there are many uncertainties how the vehicles will be organized and if handicapped persons even are able to use the same SAVs as unhandicapped persons. A possibility would be to obligate the provider of a regional SAV service concept to provide parallel services for handicapped persons to the same conditions of economic and service aspects. Further, the system has to prevent the exclusion of people that are not able to book services on an app or other technological solutions. Today, services like some ridesharing or traditional public transportation provide hotlines for ticket booking and obtaining information. In both aspects the regulator does not need to adapt the present regulatory context, as these stakeholder's needs, like the access of handicapped people to public transport or the guarantee of public transport services in peripheral and mountainous regions, are represented in the current law for the provision of public transportation in general. This will be the task of the service provider.

In the present situation, the Swiss Confederation and the cantons subsidize unprofitable lines in the regional public transportation. Our estimations show that subsidies for a combined concept with SAVs and S-train used in regional public transportation would be obsolete if one enterprise provides both transportation modes. Today, S-train services cannot be provided with gains and therefore need subsidies. By taking away the driver's task in S-trains, the cost-efficiency can be slightly increased, but not to a break-even. The cross sourcing between SAV and S-train service is one solution seen in this research to relieve the Swiss Confederation and the cantons from subsidizing regional public transportation services. The resulting gains then open up the question of the usage of the gains: will it be possible to cross-subsidize different serviced regions of one single transport enterprise or are the transport enterprises forced to pay their gains in a national project fund. A project fund could have for example the goal to help the Swiss confederation and the cantons in the funding of national and cantonal public transportation infrastructure projects. Political institution need to solve these questions in the next years, in favour of ensuring attractive public transportation services in rural areas.

With this paper, we showed how the regulator might react to new SAV services, with different open points. The state and the cantons as regulator will have the duty to regulate SAV services in the way that the population has the optimal benefit and a high quality service. From today's point of view, we cannot suggest who will be the provider of a proposed regional SAV service network including the S-train infrastructure. Nevertheless, transportation operators would need to establish new knowledge on on-demand public transportation in order to be ready to compete with new upcoming players that already have this knowledge. Yet new players may have the difficulty to receive the same support from the population in a region, which established transport operators have built up over time.

Declaration of competing interest

None.

CRediT authorship contribution statement

Sebastian Imhof: Writing - original draft, Writing - review & editing, Investigation, Visualization. **Jonas Frölicher:** Conceptualization, Methodology, Investigation, Data curation, Visualization. **Widar von Arx:** Funding acquisition, Supervision, Conceptualization.

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INTEGRATION OF RIDESHARING WITH PUBLIC TRANSPORT IN RURAL SWITZERLAND: PRACTICE AND OUTCOMES

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Integration of ridesharing with public transport in rural Switzerland: Practice and outcomes

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ABSTRACT

Using advanced technologies, ridesharing has transformed transportation in many cities. The effective integration of ridesharing into public transport systems can provide an opportunity for public transport authorities to solve the common problem of rural transport, namely poor accessibility due to the dispersal of the population. However, literature on the integration of ridesharing with public transport is rather scant. At the same time, while ridesharing has been extended to rural communities, so far this has attracted little research. To fill in these gaps, this paper seeks to explore the practice and outcomes of integrating ridesharing with public transport. The analysis is based on a case study of a community-based ridesharing scheme in four rural municipalities in central Switzerland. Using a mixed methods approach, the key findings show the public transport authority designing the integration with a goal to complementing public transport with ridesharing. To achieve this goal, three crucial approaches were adopted: the provision of information on the ridesharing scheme, the integration of ridesharing notice boards into the local bus stop and regional railway station networks; and the price strategies as a means to signify a contractual relationship between rider and driver and to reduce a potential competition. Even though ridesharing use is still only moderate, the authorities are satisfied with the outcome and do not consider cost-effectiveness to be important.

Introduction

Although ridesharing is far from being a new mode of transport, with the appearance of mobile technology and real-time informa-tion (Chan and Shaheen, 2012; Henao and Marshall, 2018) it has chan-ged the transportation market in many cities, especially in providing a reliable and affordable service in neglected city areas (Hall et al., 2018). Along with this significant gain, ridesharing also creates challenges for the transport authorities in terms of demand management. On the one hand, we have witnessed strong protests by traditional taxi-drivers against ridesharing companies like Uber on the basis that ‘uberization’ threatens their livelihoods (Malalgoda and Lim, 2019; Srinivasan, 2019). Alongside these protests there are also disputes over authorization to operate (Contreras and Paz, 2018). On the other hand, empirical studies of the impacts of ridesharing provide contradictory findings. Some studies report that ridesharing attracts riders away from public transport (Franco et al., 2019) and increases vehicle miles travelled (Henao and Marshall, 2018) and traffic congestion (Hall et al., 2018), while others claim the opposite (e.g. Hall et al., 2018; Feigon and Murphy, 2016; Chan and Shaheen, 2012).

However, these studies have primarily focused on cities and major ridesharing companies. To date, little research has been conducted in a rural context, even though ridesharing has been extended to rural communities (Hofmann and Daskalakis, 2019; Joseph, 2018). It is therefore of great interest to explore alternative ridesharing models in rural areas.

Public transport in rural areas worldwide faces a common problem of poor accessibility due to the dispersal of populations (Nutley, 2003; Petersen, 2016). Although Switzerland, like other countries in western Europe, has higher rural densities (FSO, 2014), its public transport services in rural areas are still characterized by low frequencies, limited operating hours and indirect routes (Petersen, 2012). Public transport users face the first/last mile problem (Reck and Axhausen, 2019). Poor public transport services also cause a high dependence on private cars. Nevertheless, around 22% of the Swiss rural population do not own a car (FSO, 2017), leaving the travel needs of the non-car population, as

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well as the elderly and young people,[1] unmet. Meanwhile public transport authorities are increasingly being pushed to improve the efficiency and effectiveness of how public transport is organized. They are already required to ensure the provision of public transport to meet a range of social policy goals, such as social equality and sustainable mobility (Chen et al., 2017; Docherty et al., 2018). The effective integration of ridesharing into the public transport system can provide an opportunity for the public transport authorities to improve accessibility and to increase public transport usage in rural areas by addressing the first/last mile problem (Stiglic et al., 2018), and managing ridesharing as a complement to public transport as seen later in the empirical part of this current paper. Yet the literature on the integration of ridesharing and public transport is rather scant. Moreover, to persuade the authorities to pursue this solution, future research should document successful practices through case studies (Murray et al., 2012).

Against this backdrop, the present paper seeks to explore the practice and outcomes of integrating ridesharing with public transport in a rural context. We first pay special attention to the ways in which key stakeholders cooperate with each other in designing and implementing the integration process. We then look at the outcome of the integration by means of a descriptive analysis. Because identifying suitable geographical areas plays a crucial role in designing the integration of ridesharing with public transport, we also examine the impact of factors in the built environment on ridesharing use. To do so, we adopt a mixed methods approach by combining qualitative interviews with data on level of demand and geographical information. The analysis is based on a case study of a community-based ridesharing scheme, Taxito, in four rural municipalities of central Switzerland. Our findings highlight that filling a gap in public transport and mitigating outmigration to cities are the most important reasons for integrating ridesharing with public transport. Even though ridesharing use is at present modest in amount, the authorities are satisfied with the outcome of this scheme and do not consider cost-effectiveness to be important. Instead they are concerned much more with how to design the integration such that ridesharing should complement and enhance the use of public transport. Our paper also enriches knowledge of the associations between ridesharing and the built environment, another underexplored research area (Yu and Peng, 2019).

The remainder of the paper is organized as follows. Section 2 briefly introduces the ridesharing terminology, the classification of ridesharing models, the impacts of the built environment on ridesharing, and the integration of ridesharing with public transport. Section 3 describes the context for the study, followed by a presentation of the data and methods used in Section 4. Section 5 discusses findings about the actual integration process and its outcomes. Section 6 assesses the implications for policy-makers in integrating ridesharing with public transport in a way that increases use of the latter.

Literature review

As mentioned previously, the integration of ridesharing with public transport is still under-researched. This literature review therefore adopted an integrative review method to provide a knowledge base and to present insights from different integration models. We begin with the terminological distinction between ridesharing and ridehailing. Both ridesharing and ridehailing refer to carpools (or vanpools) in which two or more individual travelers share a journey in a private automobile. However, ridesharing differs from ridehailing in its financial goals and types of travel route. Ridesharing is non-profit because the payment only covers part of the driver's costs. Conversely, ridehailing by, for instance, Uber, Lyft or Grab is a variation on the for-profit taxi. In a ridesharing system, the driver and the passengers share a common route (origin and/or destination); conversely ridehailing drivers typically do not have the same destination as their passengers (Chan and Shaheen, 2012; Clewlow and Mishra, 2017).

Based on modes of operation and participants' relations, Chan and Shaheen (2012) classify a ridesharing scheme into three subgroups. The 'acquaintance-based' carpool is formed by families, friends and coworkers. The 'organization-based' carpool is arranged around a formal institution: to use this service, formal membership or a visiting organization's website is required. The 'ad-hoc' form of ridesharing involves casual carpooling in which the driver and the passengers do not know each other. Membership is not required. The shared rides are organized by various mechanisms such as self-organization, notice boards/meeting points and computerized ride-matching systems. Because of the characteristics of the case study, this current paper only focuses on the integration of ridesharing with public transport.

Rural areas lag behind urban areas on digitalization due to their physical remoteness and low population densities (Salemink et al., 2017). The available ITC infrastructure in rural regions influences the technologies adopted by ridesharing schemes. In addition, unlike urban areas, where ridesharing services are more individual-oriented and profit-oriented, ridesharing models in rural areas are often characterized by 'community participation, individual altruism and collaborative initiatives' (Joseph, 2018, p. 3). A study conducted in rural Scotland also reports that strong local social networks have positive impacts on the feasibility of ridesharing (Gray et al., 2001).

Previous research has shown that the built environment has certain impacts on travel behavior (Thao and Ohnmacht, 2019). However, the relationship between the built environment and ridesharing remains under-researched (Yu and Peng, 2019). While empirical evidence from a few existing studies confirms the impacts of the built environment on ridesharing behavior, findings on the magnitude of the impact proved contradictory. Conducting a study of ridesharing in Texas, Pu and Peng (2019) claim that there are strong associations between the built environment (density, land use, infrastructure and transit accessibility) and the demand for ridesharing. However, a study of ridesharing in Los Angeles conducted by Brown (2020) indicates relatively weak impacts of built environment factors on ridesharing, in comparison to neighborhood socioeconomic characteristics. These two studies were conducted in a city context. In rural settings, there have been no studies of this issue to date. In the empirical section of the paper, we will provide initial findings from our case study of four rural municipalities in central Switzerland.

In practice, several ridesharing models have been developed as complementary to public transport services in rural areas. For example, Carlos was the first ridesharing service to be implemented in a non-urban context in Switzerland. It was simply incorporated into local and regional public transport services by installing call boxes around bus stops and railway stations. The project was ended after the pilot phase (2002–2005) due to the long waiting times, weak communication and low demand (Hofmann and Daskalakis, 2019). The Mobilfalt ridesharing scheme, implemented in 2013 in north Hesse, Germany, has achieved stronger integration because it is combined with the routes and timetables of local and regional public transport services. It bundles not only private cars but also taxis with public transport modes (Benz and Kepper, 2019). The Garantiert Mobil ridesharing scheme implemented in the south of Hesse goes a step further in being fully integrated into local and regional public transport services (routes, timetables and tariffs). Besides private cars and taxi, it bundles rental cars with modes of public transport (Krämer and Weiss, 2019). Other common characteristic between Mobilfalt and Garantiert is the active involvement of local transport agencies and the municipal authorities, which finance a large share of the operating costs, thus reducing fares for riders (Benz and Kepper, 2019; Krämer and Weiss, 2019).

[1] The number of Swiss people applying for driving licenses has declined in recent years. In 2017, this figure fell by 2% for the whole population. The strongest reduction (3%) was in the young population group (ages 18–24) (ASTRA, 2018).

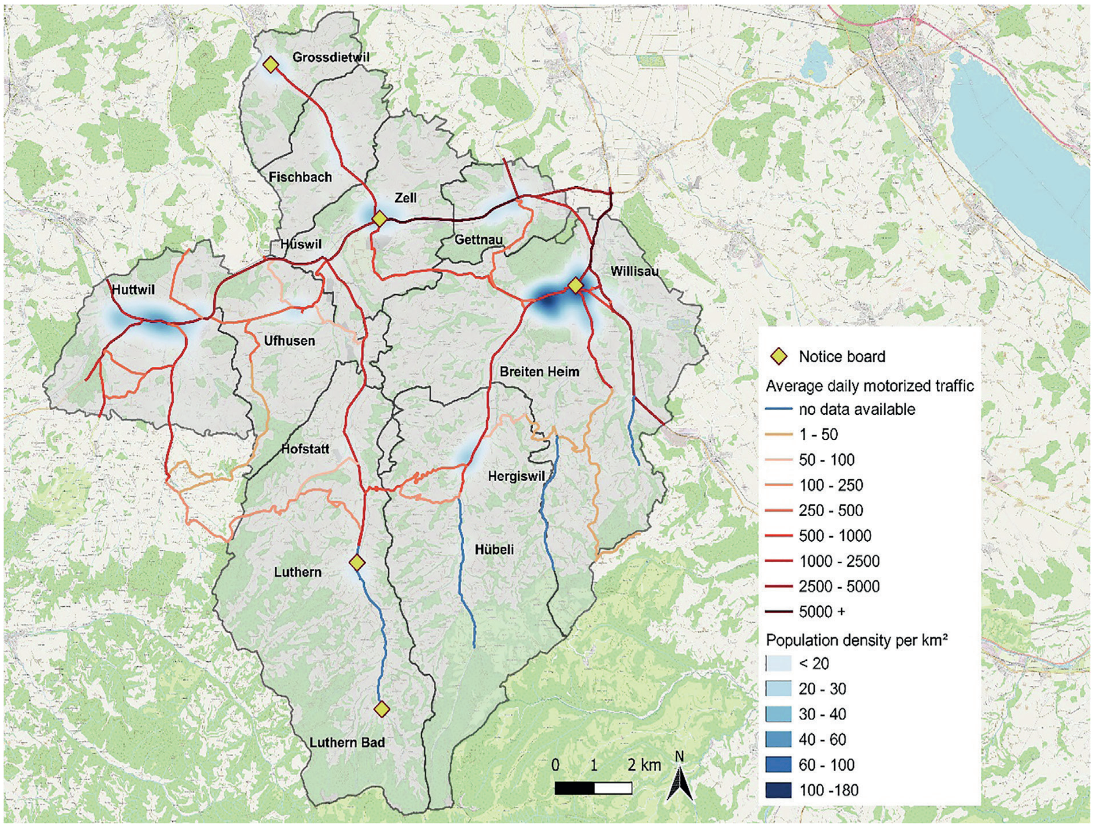

Fig. 1. The area of study.

A survey of public transport agencies and ridesharing operators in the United States conducted by Murray et al. (2012) is one of a few studies devoted to the integration of ridesharing with public transport. According to these authors, bridging the gap in transit services in areas with sparse populations and addressing customer demand are the most important reasons for ridesharing operators and public transport agencies to cooperate. To evaluate the outcome of the integration, ridesharing services are commonly used by both ridesharing and public transport agencies. For the latter, cost-effectiveness is reported as being less important. This suggests a reason why few public transport agencies have considered substituting ridesharing for a fixed route as a cost-saving measure.

The study context

In the past few years, several pilot projects (e.g. Taxito, Ebuxi/mybuxi, Kollibri, sowiduu) promoting the integration of on-demand mobility with public transport have emerged in Switzerland. These projects have been implemented in urban, peri-urban and rural areas and are varied in their technological characteristics and product design, but all seek to achieve synergies between on-demand mobility and public transport. On-demand bus and ridesharing are designed to combine with local bus routes and/or to connect with regional railway stations. It is therefore not surprising to see the strong involvement of public transport operators like the Swiss Federal Railways (SBB), PostAuto,[2] and cantonal and regional public transport associations. Besides their duty to meet customer demand, by becoming involved in these projects, public transport operators can increase their customer base and protect their market positions. Project stakeholders have formed a working group to share practical experiences and to stress the potential of this mobility solution to the Federal Office of Transport.

The case study for this paper is Taxito, the successor to the Carlos ridesharing scheme mentioned earlier. A key feature of Taxito ridesharing is that it aims to complement public transport and operates in areas with no or limited public transport services. Taxito has the characteristics of a community-based, organization-based and ad-hoc ridesharing scheme. It requires no membership registration for either riders or drivers. However, if the driver wants to receive a free highway charge sticker (worth CHF 40) and payments (CHF 1 per ride), he or she can register at the operator's website. To use Taxito ridesharing, a rider walks to the nearest Taxito notice board and sends the Taxito platform a destination code via mobile phone. The destination name will be lit up on the notice board. A driver sees the destination and can spontaneously decide whether or not to take the rider. To ensure security, the rider must send the vehicle's registration number to the Taxito platform. The rider must pay CHF 2 per ride, which is directly charged by a mobile network operator. The price can cover only a small proportion of the operating costs.

We chose Taxito for our investigation because it is the most widespread ridesharing scheme to operate in low population density areas of Switzerland. This suggests that Taxito has certain advantages that other ridesharing schemes do not. In Switzerland, Taxito is currently operating in Luthern, Willisau, Zell and Grossdietwil (Canton Lucerne), Maladers (Chur), Hé Léman (Geneva) and Emmental-Entlebuch (Bern and Lucerne). We selected Taxito's activities in the four rural municipalities of Luthern, Willisau, Zell and Grossdietwil for investigation here. The first three municipalities were the first where Taxito began operating in June 2015. This timeframe can be considered long enough to be able to evaluate the outcome of the integration of Taxito ridesharing with local public transport. Furthermore, other operational areas cover either part of some agglomeration or are

[2] PostAuto provides rural and regional bus services throughout Switzerland.

still in the pilot phase. However, we included Grossdietwil in our study, even though Taxito ridesharing only started in this municipality on 30 December 2019. This is because we are interested in knowing why Grossdietwil decided to participate in the Taxito ridesharing project at a much later date, even though it is located in the same neighborhood and faces similar problems with public transport.

As can be seen in Fig. 1, the municipalities all have low population densities, ranging from 20 person/km^2 in Luthern (and Luthern Bad) to 180 person/km^2 in Willisau. Due to low demand, the quality of public transport services is rather poor. There is a regional train connection serving the traffic corridor Willisau – Gettnau – Zell – Huttwil, but it only runs once an hour and every half hour at rush hours. A bus line serves the traffic corridor Zell – Hüswil – Luthern – Luthern Bad, but it runs much less frequently, only five times on weekdays and four times at weekends. Another bus line serves the traffic corridor Hüswil – Zell – Grossdietwil with a direct connection seven times on weekdays and twice at weekends.

Like other rural areas, the share of individual motorized traffic in total traffic volumes is high in these communities. At the same time, the average vehicle occupancy rate is rather low, at 1.37 person/car. These factors provide favorable conditions for the implementation of a ridesharing service.

With its very sparse population density and therefore very poor public transport services, Luthern was the municipality where the integration of Taxito ridesharing with public transport was initiated. Luthern has two notice boards, instead of one notice board as in the other three municipalities. From each notice board, riders can request a trip to different destinations in the neighborhood.

Data and methods

In this study, we have used a mixed methods approach. To explore the ways in which the public transport authorities cooperates with the Taxito company in implementing the integration of ridesharing with public transport, three in-depth interviews with the founder and CEO of Taxito company, the Lucerne Transport Association[3] and a member of the municipal council of Luthern were conducted. The interviews were tape-recorded and lasted between one and two hours. These interviewees were selected because they were responsible for the design and implementation of the ridesharing service in the study area. The interviews covered the following topics: cooperation goals and activities, stakeholder involvement in the implementation process, cost-effectiveness and challenges. In addition, secondary data like technical and evaluation reports on the pilot project were also collected.

To assess the outcome of the integration of Taxito's ridesharing scheme with public transport, we used an anonymized dataset of 3562 trips recorded from 1 June 2015 to 16 March 2020.[4] For each trip, Taxito and the Lucerne Transport Association provided eight variables, as listed in Table 1 below.

The accessibility of the notice boards and destinations was analyzed in order to investigate the impact of population and employment densities on the use of Taxito ridesharing. We plotted the catchment areas for each of the five notice boards and the eight destinations by using the Open Routes Service 'ORS Tools' plug-in in QGIS. Catchment areas were defined as polygonal areas with their centroid placed on Taxito's notice boards and at the destinations on the center-most point of a transport axis within a municipality or settlement, with all their vertices placed on connected transport axes (roads, streets, paths). The catchment area is determined by fixed geographical distances (500 or 1000 m) along all transport axes from their centroid to their vertices. The shape of the catchment areas depends on the structure of the road network and therefore does not form circular isochrones. For all thirteen catchment areas, isochrones of 500 and 1000 m were calculated. The geographical distances used were chosen because they are equivalent to the accessibility of the public transport connections in rural areas. The accessibility is defined by a distance to the transport stop from the household location (FOSD, 2020). In order to investigate the proportion of the population with access to the notice boards within a walking distance of 500 and 1000 m, the population living within the areas defined by each isochrones was determined by clipping the isochrones with the dataset of Swiss statistics for the Swiss population (Statpop) (FSO, 2018a). This provides the population number on a hectare grid. This step was repeated for employees working

Table 1
Taxito trip data Taxito data, n = 3562 trips.

Variable	Description
Date	
Time of day	
Place of departure	Taxito's notice boards
Destination	Destination of the trip. No information on the actual place of arrival
Waiting time	The time from the rider requesting the service to the time confirming the successful match. The real waiting time could be shorter because the rider might not send a message immediately after being picked up
Registered rider	Yes/No. This information was included in the dataset recorded from 1 June 2015 to 9 January 2019
Registered driver	
Confirmation message	A short message sent by the rider to confirm the successful match. It might also contain the number plate of the vehicle picking up the rider. The authors of this paper received only the first two letters of the number plates indicating the cantons in which the vehicles are registered. This information was included in the dataset recorded from 10 January 2019 to 13 June 2019

To investigate the impact of aspects of the built environment on ridesharing use, we combined the demand dataset in Table 1 with a dataset for the built environment. Built environment data and sources are summarized in Table 2.

Table 2
Data on the built environment.

Variable	Description	Source
Population	Number of people living in catchment areas of 500 m and 1000 m around municipality/settlement center	(FSO, 2018a)
Employees	Number of employees working in catchment areas of 500 m and 1000 m around municipality/settlement center	(FSO, 2018b)
Point of interest (POI)	Classification of amenities in the neighborhood that can influence the use of ridesharing services, including - Company and small businesses (e.g. retail, supermarket, health service) - Restaurants and entertainment - Residential areas (e.g. camping site, hotel, retirement home) - Public organizations (e.g. school, church, police station) - Tourist attractions (e.g. pilgrimage destination, tourist information, animal zoo) - Infrastructure and other (e.g. parking, gas station, fireplace)	(Openrouteservice, 2020)
Regional railway network	Location of regional railway stations	(SBB, 2020)
Daily motorized traffic volume	Individual traffic model with average daily traffic	(FOSD, 2017)

[3] The interviewee's identity was concealed at the interviewee's request.
[4] From 17 March 2020 to 24 September 2020, the Taxito ridesharing scheme had to suspend its services due to prevention measures connected with Covid-19 pandemic. This was because the local authorities considered Taxito to be a public transport service.

within the catchment area defined by the isochrones in order to determine the number of employees with access within a walking distance of 500 or 1000 m by using the dataset of Swiss statistics for the structure of enterprises (Statent) (FSO, 2018b). This provides the number of employees on a hectare grid. The same analytical procedure was carried out for the destinations.

To explore the impact of land-use diversity on ridesharing, we first counted the points of interest (POIs) in the immediate vicinity of each notice board and destination by using the POI application programming interface (API) Openrouteservice (2020). Adapting the categories of POIs by Kong, Zhang and Zhao (2020) for rural areas, we assigned each POI to one of the six categories shown in Table 2. We used the POI categories to calculate land-use diversity, represented by the Shannon entropy (Shannon, 1948):

$$H = -\sum_{j}^{n} p_j log_n p_j$$

where H represents the entropy with a range from 0 to 1; *pj* is the proportion of each category of POI (j); and *n* is the number of categories, here eight categories. The higher the entropy, the higher the land-use diversity.

In Taxito's ridesharing concept, notice boards can be considered to be the places where trips originate. We plotted the number of trips recorded between a notice board and its possible destinations. In this step, we added the regional railway locations (SBB, 2020) in the municipal neighborhood in order to explore the possible impact of regional railway locations on ridesharing use. In addition, daily motorized traffic volumes and the directions of traffic were taken into consideration (FOSD, 2017) to determine the relationship, if any, between the number of trips departing from each notice board and daily motorized traffic volumes and directions.

Results

The practice of the integration process

Goals of the integration

The actors involved in the design, implementation and operation of the Taxito ridesharing scheme are the Lucerne Transport Association (VVL), the Taxito company and the local municipalities. VVL's roles in general include planning and financing public transport in the canton of Lucerne. In this particular ridesharing project, VVL is a contracting authority that sets goals and provides funds. VVL's goal is to improve public transport services in local municipalities. The agency requires a design for the integration in which ridesharing is treated as an integral part of public transport. The ridesharing service should complement public transport in terms of both frequency and routes. There is no clearly defined goal for how many trips should be undertaken by ridesharing per year. It is important to stress that the public transport authority is not attempting to reduce the ownership of private cars by introducing the ridesharing service. In fact, it relies on private cars to achieve its goals.

In addition, the main reason for improving public transport in local municipalities is that the latter expect Taxito ridesharing to reduce outmigration to cities by making village life more attractive to the local population, especially young people. They also hope that the ridesharing service can promote local tourism. Day tourists are therefore considered to be another beneficiary group, apart from local people.

Selection of a suitable on-demand mobility service

As mentioned earlier, there are several ridesharing models in Switzerland currently. VVL has also evaluated other transport service models like regular buses, on-demand buses, collective taxis (*Anrufsammeltaxi*), etc. VVL chose Taxito ridesharing because it offers a low threshold for both riders and drivers using the service. Any rider who has access to a cell phone can use Taxito ridesharing, and it can be accessed by low-income population groups such as students. It costs just 75 pennies more than a single journey on a bus ride, so that Taxito ridesharing does not compete with public transport providers in terms of price. However, the price of a journey by ridesharing must be much cheaper than a taxi ride, which is CHF 3 per kilometer. Moreover, Taxito destination display boards by means of lights increases the ride's appeal to private car drivers, thus helping to reduce waiting times. Another added value of Taxito ridesharing is that can be available 24/7 by exploiting the spare capacities of individual motorized traffic.

Identification of a suitable neighborhood

To identify a suitable neighborhood in rural areas, VVL adopted a phased adoption approach. The agency considered the Taxito ridesharing scheme to be a new mobility solution, a kind of innovation. Using the phased adoption approach, the public transport authority expects decisions to be made in a transparent manner, the experience gained then being taken into account in taking further decisions. It first conducted an analysis to evaluate the suitability of the Taxito scheme by taking into consideration the quality of its transit accessibility, population densities and daily individual motorized traffic volumes (VVL, 2014). Based on the results of this analysis, Luthern, Willisau and Zell were selected for the pilot phase. The goal of the pilot phase was to test the system and probe acceptance among the local population, the local municipalities and the regional development agency, rather than gaining large numbers of riders. After receiving positive feedback from the municipal councils and the regional development agency, VVL decided to start the pilot phase.

Location of notice boards and destinations

The most important task in the pilot phase was to decide the location of the notice boards. There is general agreement among VVL, the municipalities and Taxito that the notice boards should be integrated into the local public transport network. The location must be identified on the basis of the quality of transit accessibility, that is, a poor public transport connection or none at all. A high daily individual motorized traffic frequency is another important criterion for location choice. The location must allow private car drivers to follow the road transport regulations, for instance, no prohibition on stopping and the necessary distance to crossroads. Ideally, individual motorized traffic should be sorted by direction of travel and connected to destinations requested by Taxito riders, thus contributing to more successful 'matching'.

At the same time, the location should not disturb the public transport service. The location should also have pedestrian crossings, so that riders have easy access to the notice boards. Furthermore, the location must guarantee certain security for riders (see Picture 1). During the pilot phase, the location of the notice boards must be adjusted to end-user demand. In principle, there should be one notice board for every municipality. However, if demand increases, additional notice boards can be installed. As a result, except in Willisau, where the notice board is located around 200 m from the railway station, in all other municipalities, they are located at the bus stop. Thanks to the rigorous criteria for the choice of notice board locations, until now no damage, accidents or assaults have been reported.

To install the notice boards, budget applications and an approval request had to be submitted to the municipalities to reconstruct the road space. Approval for the installation of the illuminated signboard had to be obtained from the cantonal road traffic authorities. At this stage, the municipalities were closely involved in the decision-making process because they had good knowledge of local conditions and understood the needs of their communities. They also provided infrastructure and budgets for the installation of the notice boards. The Taxito company supported the municipalities in determining the location of the notice boards and destinations. The company is in charge of maintenance and the provision of a replacement in the event of a defect.

Picture 1. Taxito board (Source: Keystone/Urs Flueeler).

Each Taxito point can connect to several destinations (see Fig. 7 below). Locations of destination are decided based on the following principles: using Taxito ridesharing as a means to overcome the first/last mile problem by transporting villagers in the municipalities to/from regional public transport hubs and as a means of direct connections with other villages in valleys to avoid indirect connections associated with local bus services (for instance Luthern Taxito point – Hergiswil). Destinations are therefore located near regional railway stations and/or in villages in the valleys.

Acceptance of local people

The success of the Taxito ridesharing scheme depends also strongly on the goodwill of individual car-drivers and the local people's willingness to use the service. The stakeholders therefore see local people as an important factor in the success of the integration of ridesharing with public transport. They decided that the municipalities should take responsibility for promoting public acceptance of the scheme. As 'insiders', they have direct access to the local population. However, as the municipalities had little experience in staging communication and awareness campaigns, Taxito worked closely with the municipalities in this activity. It provided the municipalities with communication equipment, for example, and supported them in organizing and holding marketing and communication events for the launch of the pilot phase.

A series of intensive communication and marketing activities were carried out to raise awareness and increase acceptance of Taxito ridesharing. Two weeks before launching the pilot phase, a flyer introduced the goal of Taxito's scheme and explaining how it works was sent to each household in the municipalities. Awareness events to introduce the concept and functions of ridesharing were held at local schools. Meanwhile, several media press events were organized at the invitation of representatives of local media agencies, like newspapers and television and radio programs before and at the launch of the pilot phase, at the opening of the first notice board and before the ending of the pilot phase. The launch of the pilot phase even received attention from national media agents. Meanwhile, the testimonies of local people as both drivers and riders were collected and used in communications and advertising concerning the ridesharing.

Participation in costs

As the contracting authority, VVL bore the costs of the initial analysis, the pilot phase, and the marketing and communication activities. It also pays for renting four Taxito notice boards (VVL, 2014). The municipality of Grossdietwil pays for the notice board itself. The municipality decided to join the Taxito ridesharing network having observed the good experience with it in the neighborhood.

The municipalities finance the installation of notice boards and provide solar panels for them. The Taxito company makes its revenue by renting out the notice boards and by charging 0.1 CHF per ride. The remainder of a charge per ride goes to a telecom company and the registered driver or, if the charge is waived, to VVL. This suggests that the Taxito company makes a very low profit, but it still provides the ridesharing service because it sees itself as a social entrepreneur promoting an environmentally friendly mobility solution that contributes to the attractiveness of village life.

To find out whether the Taxito ridesharing solution is a cost-effective solution or not, we calculated the total costs of the entire ridesharing scheme and the cost per ride, based on the costs provided by the interviewees. The rent for one notice board is 5988 CHF in the first year and 3950 CHF for each of the following two years. The installation of one notice board costs 4450 CHF. In total, in the first three years and for all five notice boards, the entire Taxito ridesharing service will cost 91,690 CHF. The costs of planning and obtaining approval of the locations is not included because it is too complicated to estimate the human resource costs of local authorities.

Fig. 2 shows the development of the costs per ride and the total costs of the service. In the first three years, the ridesharing service is

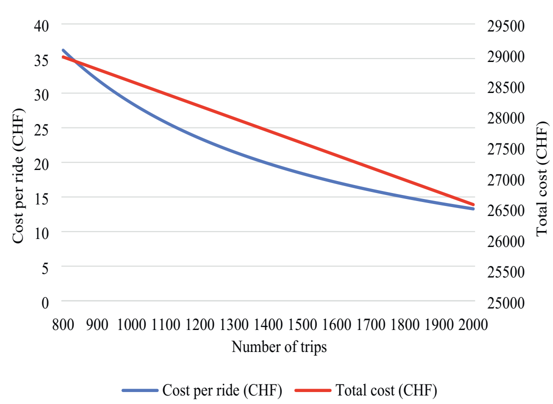

Fig. 2. Cost of Taxito ridesharing service.

shown as being used by an average of 708 passengers a year, without the Grossdietwill notice board. By adding 180 passengers who would use the Grossdietwill notice board, we arrive at a total of 888 passengers using the ridesharing service per year. The total cost (fixed costs minus fare) per ride is around 32 CHF. That is a high amount. However, the total cost would be reduced over time if the number of passengers remained stable or increased. Nevertheless, the total cost of the Taxito ridesharing service is still much lower than a single regular bus line that runs five times a day and would cost 1 million CHF per year to run in rural areas, with just 30% of the cost being covered by the fare.

Collecting the fare of 2 CHF per ride is actually expensive due to the high roaming cost charged by telecom providers. However, VVL does not want to provide a free-of-charge ridesharing service. Beside competition avoidance, appreciation is another reason to charge a fare: the fact that the ride costs the rider something establishes a contractual relationship between the driver and the rider. Ridesharing trips should not be perceived as 'charity' work, according to the contracting authority.

Challenges and weaknesses

Optimization of the ridesharing service in regular operation has proved to be a big challenge. For example, the location of the notice board in Willisau is not considered suitable because potential riders have to walk some distance away from the center of the municipality to get to the notice board. However, it has not been moved somewhere better, mainly because no clear responsibly for doing so was established after the pilot phase. Furthermore, the number of notice boards are viewed by the Taxito company as requiring expansion. The introduction of more notice boards would increase ridesharing use. The authorities agree on this point, but they have other priorities than pursuing this goal. One reason for the reluctance to expand is that ridesharing could become a competitor to local public transport operators.

The Taxito company itself speaks of a relative high level of acceptance and sensitization of the local population to the relevance of ridesharing. However, it is difficult to maintain the acceptance and willingness of drivers to take part. The basic belief that 'Taxito brings something to our region – we participate' (Taxito founder) must be regularly communicated to the public. While Taxito is relatively well known in very remote areas in those municipalities without public transport services, drivers in regional centers (where regional railway stations are located) hardly know anything about Taxito's ridesharing scheme. Since the completion of the pilot phase, no institution has been made responsible for marketing the scheme. There is no service mandate for this, and accordingly no responsibility and budget. Nonetheless, except in the Luthern municipality, which is affected by outmigration, awareness activity is still somehow carried out at a certain level.

Since Taxito is not integrated into public transport's central communication channels (timetable and ticketing channels), there is an acute danger of the service being neglected. During the Covid19 lockdown, Taxito was banned from operating. However, this information was not shown on the notice boards. Riders did not receive any information via mobile phones. Only by visiting the website of the Taxito company could they access to this information. Therefore, the interviewees agree that communication and marketing activities should be implemented after the pilot phase in order to maintain local people's participation in Taxito's ridesharing scheme, especially in the regional centers.

While Taxito sees simplicity of use as a central and unique selling point, the municipality finds it rather complicated. Because the rider has to enter a message code to activate the notice board and send the vehicle's number plate.

Satisfaction with ridesharing

Despite the above challenges and weaknesses, VVL is satisfied with the outcome. The contracting authority views a low but constant number of trips, given the sparsely populated area and low level of marketing effort, as positive. Even though the municipalities agree on this, there is nonetheless some skepticism. One municipal councilor reported that he has never seen anyone at a bus stop and accordingly has never taken anyone with him. There is even a certain distrust of the statistics because, 'if it were needed, you would have seen people?' As our descriptive results below show, local people do use the ridesharing service, but only at a modest level. Tourists seem to use the service more often. Taxito ridesharing can probably be seen as an enhancement of tourist provision in the municipalities.

VVL is also satisfied that the Taxito ridesharing service does not compete with local public transport once it has been in operation for longer. Instead, it increases the modal split in local bus services in the third year of the ridesharing operation, though at a very modest rate (VVL, 2017). As the notice boards are at bus stops, it sometimes happens that riders take the bus while waiting to be picked up by the ridesharing service if a bus arrives beforehand.

The use of Taxito ridesharing

During the period from June 2015 to March 2020, 3562 trips were made using Taxito ridesharing. Of 2215 trips travelled from 2015 to 2018, only 99 were made by registered riders and only 36 by registered drivers. Of 302 recorded trips containing confirmation messages, 85 trips only had information using the words 'OK', 'good', 'go' or 'car'. The remaining 217 trips were undertaken by local drivers (61%), drivers from neighboring cantons (17%), drivers from foreign countries (15%) and buses (7%).

As can be seen in Fig. 3, the number of trips fluctuates overtime, reaching a peak in the second year. This could be due to the effects of the marketing campaign at the end of the pilot phase in which awareness of Taxito ridesharing was widespread in the local municipalities and nearby neighborhoods. For the last ten months of operations (June 2019–March 2020), seven hundred trips were made, roughly as many trips as in each of the two previous years. This increase in demand may suggest that Taxito ridesharing has become an established name and aspect of local public transport services.

On average, riders have to wait less than four minutes to be transported. This is a very short waiting time when compared to the low frequency of public transport services. The waiting time is expected to decline still further in the first four years but to increase again in year five. There are some trips for which riders had to wait more than hour, usually late at night or early in the morning.

Fig. 4 shows that most trips are made between 15:00 and 19:00 and between 21:00 and 23:00. There is no great demand for ridesharing during the morning rush hour. This is because local buses have more

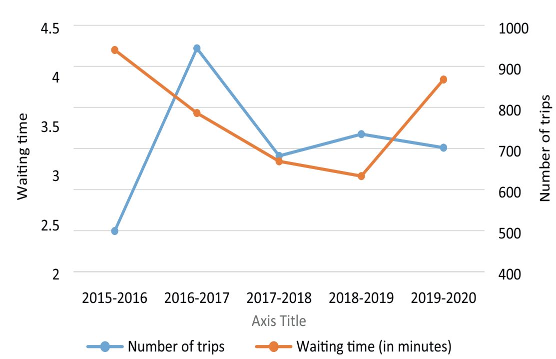

Fig. 3. Number of trips and waiting time.

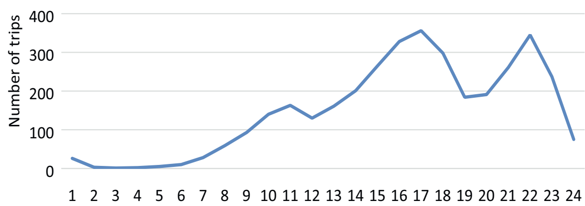

Fig. 4. Daily time travel.

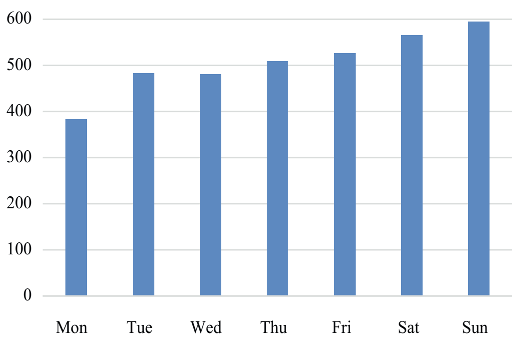

Fig. 5. Distribution of trips throughout the week.

frequent services at rush hours. It seems that riders use Taxito ridesharing at night hours mainly for non-work-related trips.

As shown in Fig. 5, the demand for Taxito's ridesharing scheme gradually increases throughout the week. The high demand at weekends may be because of the even lower frequencies of public transport services on Saturdays and Sundays.

Impact of the built environment on Taxito ridesharing use

Accessibility of notice boards and destinations

The notice board in Willisau is accessible to more than 2000 people living and over 1000 people working at a walking distance of 500 m (see Figs. 6a and 6b). Doubling the walking distance also doubled the population and number of employees with access to the notice board. Similar results were found in Zell. In both cases, notice board use is high, with 962 trips starting in Willisau and 1166 in Zell (see Table 3). However, a low level of population and employee accessibility to a notice board does not necessarily correlate with a low usage for that notice board. Of the five notice boards, that in Luthern Bad had the lowest population and number of employees in both of its catchment areas, but it had the second highest usage, with 1006 trips. The notice board in Luthern recorded 408 rides, less than Luthern Bad, despite its larger population and number of employees with access to it.

Regarding user demand for travel to different destinations, despite having both a high population and a high number of employees, Huttwil shows only a very low number of trips. A similar relationship can be found in Gettnau (see Table 3 below). This suggests that there is no direct correlation between the size of the population or the number of employees and the number of trips to a destination. The potential demand for travel to Luthern Bad, Hübeli and Hüswil can be considered low, taking into account the number of possible users reached. However, the actual level demand suggests the opposite: the numbers of recorded trips to these destinations are among the top five. This

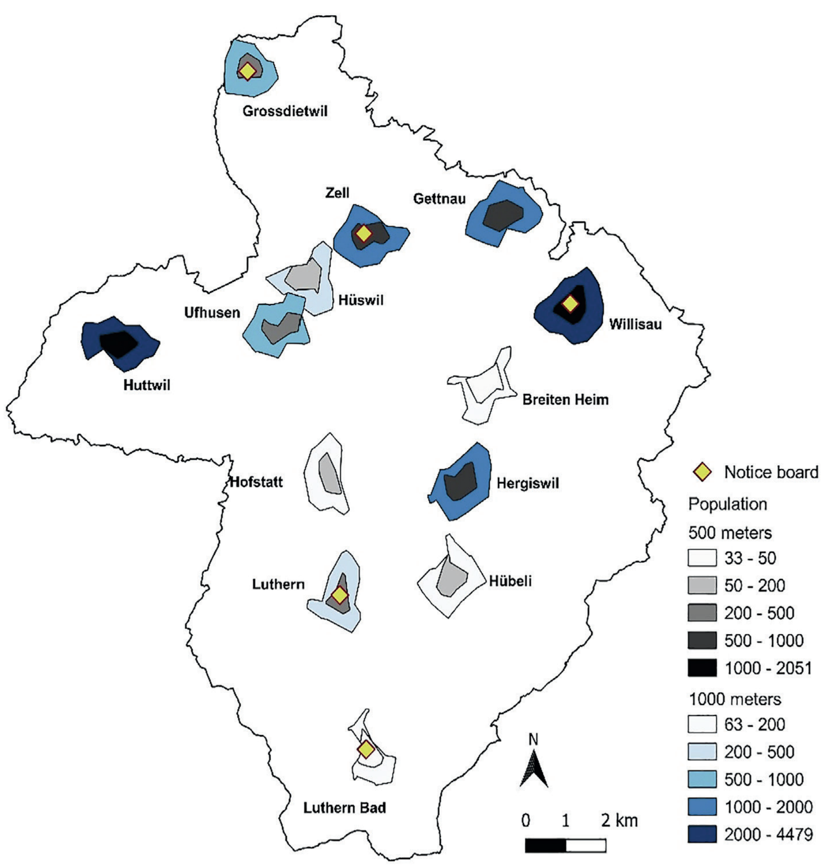

Fig. 6a. Population in catchment areas of 500 and 1000 m of notice board locations and of destination locations.

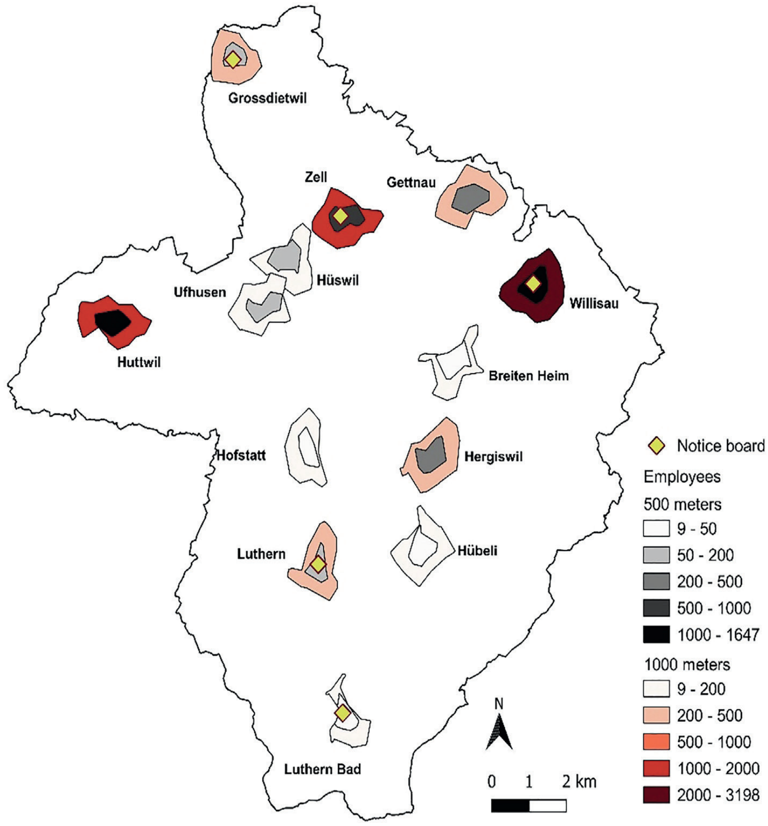

Fig. 6b. Employees in catchment areas of 500 and 1000 m of notice board locations and of destination locations.

Table 3
Land-use diversity at notice boards and destinations.

Destinations	Total trips from notice board	Total trips to destination	Shannon entropy H
Grossdietwil	20	857	0.90
Luthern	408	29	0.81
Willisau	962	42	0.90
Luthern Bad	1006	691	0.62
Zell	1166	334	0.90
Gettnau	–	5	0.70
Ufhusen	–	9	0.72
Hofstatt	–	26	0.36
Huttwil	–	76	0.84
Breiten, Heim	–	80	0.58
Hergiswil	–	134	0.88
Hübeli	–	309	0.39
Hüswil	–	970	0.64

comparison between population and number of employees within 500 and 1000 m and trips ending at destinations show no clear patterns.

Land-use diversity

As shown in Table 3, the notice board locations have a high diversity of land uses, except in Luthern Bad (Shannon entropy H = 0.62). Comparing the total trips departing from each notice board, no association between the land-use diversity index and the demand for Taxito ridesharing was found. A low level of land-use diversity does not imply low use of the notice board.

For the destinations, a similar unclear relationship between the number of trips and the land-use diversity index was observed. A higher land-use diversity index does not lead to a higher number of trips to a destination. For example, Willisau (Shannon entropy of H = 0.90) was found to be the final destination of only 42 trips, whereas Hüswil, with a relatively lower Shannon entropy (H = 0.64), is the most frequent destination in the entire Taxito network.

Daily individual motorized traffic and regional railway stations

Fig. 7 shows two highly used traffic flows in the ridesharing network in the neighborhood. The highest number of trips was observed between Zell and Grossdietwil (852 trips), followed by trips between Luthern Bad and Hüswil (770 trips).

Of the total of 27 possible connections between notice boards and destinations, seventeen connections recorded fewer than fifty trips. They are therefore considered connections of low demand. Of these seventeen low demand connections, six are between two railway stations. However, the presence of a regional railway station at either of the two ends of a connection (either near the notice board or at the destination) appears to be correlated with a higher number of trips in some cases. The destination of Hüswil, which has a railway station, was the most frequent destination (see Table 3). The number of trips from Luthern Bad to Hüswil and from Zell to Grossdietwil are the two most frequent connections in the ridesharing network. In both cases, the regional railway station is situated at the end of a traffic axis going out of the local valley.

As can also be seen in Fig. 7, the existence of a well-frequented route has a positive impact on the success of ride 'matching'. If a route

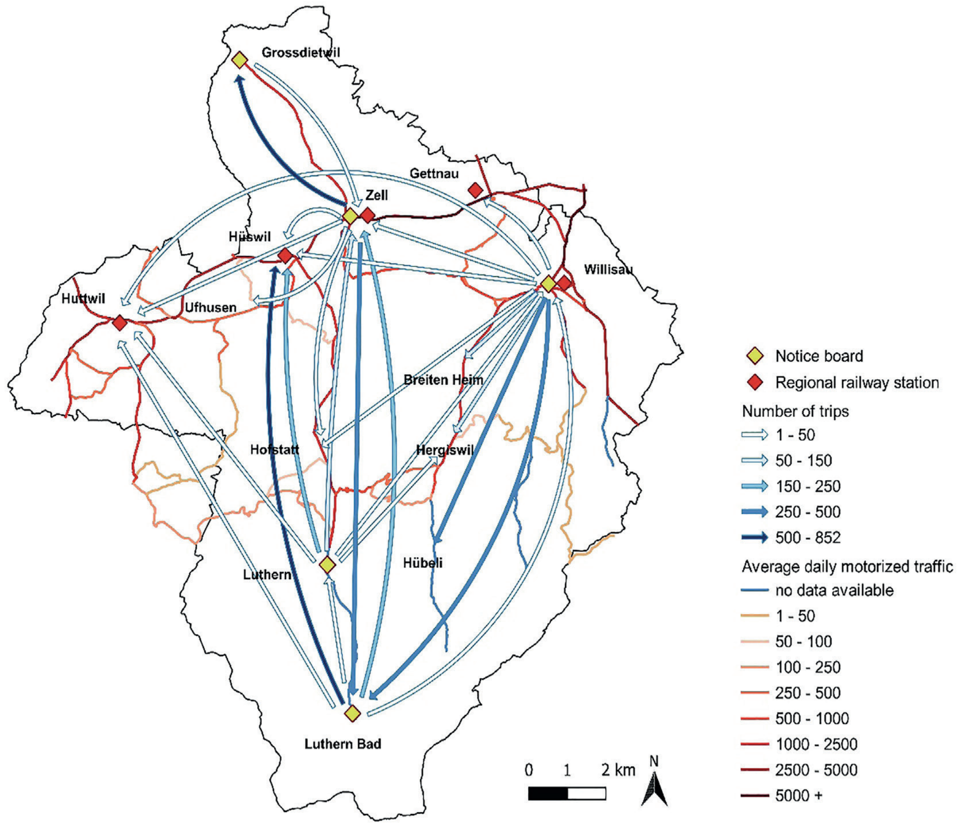

Fig. 7. User demand of traffic connections between notice boards and destinations in relation to locations of regional railway stations and average daily motorized traffic volume.

has a higher daily volume of motorized traffic, it has a tendency to have a higher number of ridesharing trips. For example, the routes from Luthern Bad to Hüswil and from Zell and Grossdietwil have average daily traffic volumes of between 2500 and 5000 cars and the highest number of ridesharing trips, from 500 to more than 850. Likewise, a low daily average traffic volume (below 500 cars/day) on the routes used by ridesharing, e.g. between Luthern and Huttwil, appears to have a low number of recorded ridesharing trips.

Discussion and conclusion

This paper has attempted to explore the practice and outcome of the integration of ridesharing with public transport in a rural context. The findings show the public transport authority carefully designing the integration with a view to complementing public transport with ridesharing. Three crucial approaches were adopted to achieve this goal. First, Taxito's ridesharing scheme was developed and implemented in a participatory way, with strong engagement by the municipalities and local populations concerned. The provision of information on the scheme before and during the pilot phase was carried out in a series of intensive communication and marketing activities to raise awareness of local people and to encourage their participation in Taxito's ridesharing.

Second, ridesharing notice boards are integrated into the local bus stop and railway station networks. This way of integrating ridesharing services with public transport systems can promote the usage of public transport services. Instead of continuing waiting for being transported by the ridesharing service, riders can take a bus trip if the bus arrives beforehand. Indeed, a slight increase in the ridership of local bus services has been observed. Further, the connection from ridesharing notice boards with regional railway stations can bring customers to railway operators, thus promoting rail use.

The third approach is the pricing strategies. The ridesharing ticket is slightly more expensive than the bus fare but much cheaper than taking a taxi. This pricing strategy can ensure that ridesharing does not replace public transport. Empirical evidence from the demand dataset shows that the public transport agency has achieved this goal. This explains why the authority is satisfied with a relatively low but stable use of ridesharing over time. Our findings support Murray et al.'s claim (2012) that for the public transport authorities, cost-effectiveness is less important in seeking integration with ridesharing. In the context of rural Switzerland, the goal of reducing outmigration to urban areas appears to have a higher priority. Furthermore, the low fare is used as a means to signify a contractual relationship between the rider and driver, thus contributing to the appreciation of a ridesharing ride as a service rather than as a kind of charity work.

Our findings suggest that public transport operators, particularly the railway operator, can expand their customer base thanks to the integration of their services with ridesharing. Therefore, local bus and railway operators should actively work with the ridesharing operator in extending a network of ridesharing notice boards and incorporating ridesharing into their central communication channels, for instance provide information on ridesharing services on display boards at regional stations. The public transport authority (VVL) could consider to include these operators in the ridesharing scheme. For the ridesharing operator, it should propose a budget plan for communication activities beyond the pilot phase so that it can communicate with its customers when major disturbances occur such as sending text messages to its customers or regularly hold awareness campaigns.

Two aspects arose on the basis of the findings of this study that should deserve further investigation. One is why the use of Taxito ridesharing rather low despite its advantages. Does this problem lie in the acceptance of local people? We therefore propose a hypothesis that implementing regular communication and marketing efforts in rural municipalities as well as in regional centers during the service life of a ridesharing scheme is likely to increase the participation of local people and potential drivers in ridesharing. Another interesting subject for future research is the impact of built environment on ridesharing demand. We hypothesize that in a rural context, traditional built environment factors such as population and employment densities and land-use diversity have no impacts on the demand of ridesharing whereas the location of regional public transport hubs do have an impact.

The main purpose of the mixed methods approach was used as complementarity to increase the scope of the inquiry, i.e., practice and outcomes of the integration of ridesharing with public transport systems, however, quantitative findings on the use of Taxito's ridesharing support results from qualitative interviews that Taxito's ridesharing scheme is a complement to public transport. This can be seen in a moderate number of ridesharing trips and more demand for ridesharing at weekends and late evenings when local bus operators reduce their services.

Studies on transportation policies are often in favor of quantitative methods such as modelling and macro-trends (Marsden and Reardon, 2017). However, new mobility solutions can involve a complexity of policy making in realities as shown in this present case of the integration of ridesharing services with public transport systems. A mixed methods approach therefore can grasp the complexity of how transportation policies get made and implemented at the local level.

The findings of this paper are based on an exploratory study. The impact between factors of the built environment and ridesharing use has been investigated purely by means of a spatial analysis. Regression models to confirm this impact could not be carried out due to the low level of observation of notice boards and their corresponding destinations. In addition, only three qualitative interviews were conducted with the involved stakeholders. Hence, any generalizations from our findings should take these data limitations into consideration. Nevertheless, the case-study approach described here can provide insightful findings into the integration of ridesharing with public transport in rural contexts, a still rather neglected area of research.

CRediT authorship contribution statement

Vu Thi Thao: Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. **Sebastian Imhof:** Methodology, Investigation, Visualization, Formal analysis, Writing - original draft. **Widar von Arx:** Methodology, Investigation, Formal analysis, Writing - original draft.

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The interviewee's identity was concealed at the interviewee's request.

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HOW SOCIAL INNOVATIONS EMERGE IN A RIGID REGULATORY CONTEXT: THE CASE OF DEMAND RESPONSIVE TRANSPORT IN SWITZERLAND

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How social innovations emerge in a rigid regulatory context: The case of Demand Responsive Transport in Switzerland

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Abstract

Demand responsive transport solutions are considered as an appropriate way to improve rural transport systems. Those solutions often emerge as social innovations in rural areas and have the goal to provide a service for those who do not have direct access to a car. The planning process of these social innovations in Switzerland is embedded in a rather rigid regulatory framework of the public transport system. The main objective of this paper is to better understand in which way the regulatory framework of the public transport system influences the planning process of a demand responsive transport solution in a rural setting. We use the methodological approach of social innovation biographies and examine the involved planning steps that were needed to start mybuxi, a demand responsive transport in two rural municipalities in Switzerland. Our findings show that regulatory constraints dominate the final planning stage of the social innovation. The protection of the current public transport regulations hinders the federal offices to subsidize the new transport form which has direct implications on the financial sustainability of the system. The findings of this paper are crucial for the development of future social innovations in the transport sector. Knowing more about how to deal with regulatory constraints helps actors to address regulatory questions in an early stage in the innovation process.

Keywords: social innovation; DRT; rural area; experiment; regulatory context, socio-technical transition; Switzerland

1. Introduction

The provision of public transport (PT) in rural areas faces numerous challenges due to dispersed settlement structures and low population densities. These rural characteristics make it difficult to provide adequate – in terms of efficient and frequent – PT services. Demand Responsive Transport (DRT) represents an innovative solution and can replace private car trips (Mulley & Nelson, 2009). DRT is “an intermediate form of PT, somewhere between a regular service route that uses small low floor buses and variably routed, highly personalized transport services offered by taxis” (Brake et al., 2004). Compared to traditional PT options, DRT has lower overall service provision costs because the vehicle size is reduced and novel technological solutions allow greater flexibility of the services, resulting in increased attractiveness (Teal & Becker, 2011). In rural areas, DRT services often have been initiated as social innovations (SI) and tend to be operated by volunteer organizations building on strong local communities (Bock, 2016; Gray et al., 2006; Neumeier, 2017). Butzin et al. (2015) identify a variety of practice fields of SIs in the transport sector like citizen initiated PT, transport services for people with disabilities and/or elderly as well as mobility apps.

SIs are an important part of current socio-technical transitions towards more sustainable systems (Wittmayer et al., 2020) like the transport system (Meelen et al., 2019; Sunio et al., 2020). A multi-level perspective on socio-technical transitions helps us to understand how a SI may contribute to a transition towards a more sustainable rural transport system (Geels, 2004). SIs can open spaces for experimentation in form of niches challenging existing regimes. These experiments are context specific and open new possibilities to test new intervention logics and governance approaches in real-world settings (Bulkeley & Castán Broto, 2013; Wimbadi et al., 2021; Wittmayer et al., 2020). With their ability to challenge a dominant socio-technical regime, SIs as transition experiments can play an important role in reconfiguring an existing socio-technical system (Hodson et al., 2017). Yet, we need to keep in mind that DRT services are embedded in a context-specific, complex network of governance, political and regulatory environments because service provision in PT normally needs to go through various stages of approval at different institutional levels. Yet, this latter aspect has received less attention in the literature even though some authors recognized that SIs in the transport sector in particular are subject to a set of governance and political framework conditions (Butzin & Rabadjieva, 2017).

In this paper we focus on a case study of a DRT service that represents a SI, which was developed and by now implemented in two neighboring municipalities in a rural region in Switzerland. The SI we are interested in is called *mybuxi* and was successfully launched in 2019 as an on-demand ridepooling service that utilizes a smartphone application. mybuxi has the goal to provide attractive transport solutions for the local population. Even though PT in Switzerland is very well developed, especially between major destinations such as the larger metropolitan areas, services in rural areas have been subject to a reduction of lines as demand is decreasing and the services are highly cost inefficient (FOT, 2020; Office of public transport, 2013, 2017). Yet, PT services in rural areas are seen as a necessity to ensure access to transport for mobility-disadvantaged groups justifying high subsidies (Buehler et al., 2019; Mulley &

Nelson, 2009). For local authorities that have to subsidize PT routes in rural and dispersed settlement areas (Ubbels et al., 2001), new flexible forms of transport with a similar or better service quality may be an attractive solution to minimize public spending (de Jong et al., 2011). Despite positive anticipated consequences for the rural transport system, planning DRT services in Swiss rural areas is linked to several challenges and new business models are challenging historically evolved regulations and governance approaches.

The research gap that we are addressing is related to the question how in a highly protective and regulatory environment (e.g. PT) a SI is implemented and how this SI is part of a transition process. Research on DRT services in rural areas so far examined their acceptance (Avermann & Schlüter, 2019), the necessary degree of service flexibility (Sörensen et al., 2021) or influential factors on the behavior of a service usage (Wang et al., 2015). Yet, a focus on the regulatory context is missing. The provision of DRT services like *mybuxi* in Switzerland must be in line with current regulations for the provision of PT services to obtain public subsidies. As the following case study will show, the planning and the implementation of *mybuxi* was linked with regulatory constraints and challenges. Embedded in a path-dependent regulatory context, the actors of the mybuxi project had to find and plan with creative, case specific ways how the DRT service was enabled and allowed to operate in the respective setting.

In this paper we ask the following research question: How does a SI like a DRT system contribute to a transition towards a more sustainable transport environment in rural areas? Additionally, the paper provides details how complex regulations of the PT regime influenced the planning process of the SI. The remainder of the paper is structured as follows. Section 2 introduces the concept of SI, the role of regulations in SIs and how the planning process of a SI can be theoretically structured. Section 3 describes the case study of mybuxi by introducing the regulatory and spatial setting, the characteristics of the mybuxi service and the chosen methodological approach of social innovation biographies. Section 4 introduces the results on the planning process of the SI of mybuxi as well as how regulatory questions are influencing the SI. Section 5 concludes this paper, including an outlook on future research.

2. Theoretical and conceptual perspective on SIs and regulations

Social innovations represent community-based creative ways to respond to local problems such as those that arise in the context of PT provision in the rural context (Grimm et al., 2013; Kirwan et al., 2013; Moore et al., 2012; Neumeier, 2017). The withdrawal of the state from the supply of welfare services in addition to state or market failures are often considered as `unintentional` drivers of SIs as they open the possibility for new actor constellations and new forms of collaboration (Terstriep et al., 2015). SIs can only evolve based on collective action when the group of involved actors agrees on aligned interests. The existence of social networks and social capital is therefore key for a SI (Neumeier, 2012).

In the transport sector, SI initiatives are manifold and tackle challenges such as the ways in which transport can be inclusive for all members of the society and how society can reduce negative ecological impacts of individual transport (e.g. CO2 emission, noise level).

Besides direct impacts like the reduction of CO_2 emissions by introducing better transport solutions, SIs can have an impact on the transformation of socio-technical systems (Wittmayer et al., 2020). To better understand the mechanisms how SIs and other niche innovations can challenge dominant systems (regimes), the multi-level perspective was introduced (Geels, 2004). Embedded in a socio-technical landscape of an exogenous environment (like shared cultural beliefs and values), different dominant socio-technical regimes exist. Regimes are stable systems consisting of shared rules, cognitive routines, institutional arrangements, and regulations. Examples for dominant regimes are the automobility or the PT regimes which evolved over long periods of time (Geels, 2004, 2005, 2011). To challenge a regime, innovations and novelties emerge in form of niches trying to become part of or replace a regime. Those niches often have a radical and disruptive character as they are less dominated by lock-in or path dependency mechanisms than existing regimes (Klitkou et al., 2015). With their disruptive character, niches like in our case a SI can affect the regulatory environment.

Transition processes are influenced by governance processes on different levels and with different interests: involved are institutions from the territorial-specific to the national and international level (Acuto, 2015; Geels, 2012). Knowing about the possible tensions between radical change of niches and established actors and governance settings, Wittmayer et al. (2016) call for creative ways to open spaces for experimentation like SIs. By opening those spaces, roles and attitudes of actors and institutions may be reflected and challenged, supporting the evolvement and establishment of new ways of governing a sustainable future.

Hodson et al. (2017) provide an analytical framework on the possible ways how niches and existing regimes interrelate and reconfigure urban transition processes. Multiple parallel innovations and existing regimes can either compete against each other, co-exist together or even complement each other regarding the impact on the transition process (see also Schwanen, 2015). These interactions occur on three levels of analysis. First, Hodson et al. (2017) call for an understanding on configuration of socio-technical experiments and existing systems on the socio-technical environment. Experiments can either provoke struggles between new and old socio-technical arrangements (competing); the systems can happen in parallel (co-existing); or they can merge and lead to a new socio-technical arrangement (complement). On a second level, the experiments can lead to new forms of governance. Those new forms of governance can be in a competing situation with existing governance approaches and contradict each other; the forms of governance can be autonomous or loosely coupled (co-existing); or they can complement each other in a reinforcing new governance form. The third level of analysis concerns the understanding of actors and institutions regarding the concept of sustainability. Different understandings on sustainability can lead to competing situations and goals; non-conflictual understandings can occur in parallel (co-existing); or the understandings can be complementary and reinforce each other in favor on sustainability goals.

Spaces for experimentation always call for space specific regulatory frameworks (Hodson & Marvin, 2012; Wimbadi et al., 2021). Innovations – not only technological innovations but also SIs – are often influenced by the regulatory environment. Specific regulations in terms of authoritative rules, norms, standards, laws, etc. are particularly important for developing and implementing new ideas in heavily regulated sectors such as transport. Regulations here are defined as “a set of authoritative rules, some often accompanied by some administrative agency, for monitoring and enforcing compliance” (Jordana & Levi-Faur, 2004, p. 3). Regulations in transport systems address economic, safety and environmental concerns. Economic regulations concern the allocation of capital and pricing. Safety regulations focus on the operation of a transport system. Environmental regulations are related to externalities and the impact on the environment (Rodrigue, 2020). Regulatory reforms are a possibility for improving the quality of PT services (Ongkittikul & Geerlings, 2006).

The implementation of SIs can have unwanted, unforeseen outcomes (Grimm et al., 2013). Terstriep et al. (2015, p. 2) point out that “[s]ocial innovations tend to challenge institutions and thus, require an understanding of institutional order and multilevel governance that direct institutions, which facilitate or impede their implementation”. SIs always have to adopt and deal with regulations concerning a sector wherein a SI tries to evolve (Terstriep et al., 2020). An incompatible regulatory culture can constrain SIs (Hubert, 2011) and regulatory uncertainties are often considered as possible barriers to innovate for entrepreneurs (Grimm et al., 2013). Jalonen (2011) identifies being regulatory and institutional uncertainties as one of different types of uncertainty concerning innovations. Uncertainty can be a result of a lack of understanding on the way regulations may affect a SI. Gährs and Knoefel (2020) show based on the example of community energy storage in Germany that an unclear legal definition of the regulatory framework can hold stakeholders back from implementing an innovation. To deal with the regulatory uncertainties and constraints, external and non-local knowledge has to be involved in a SI (Nordberg et al., 2020).

Lo Schiavo et al. (2013) show that regulations can be subject of constant modification in favor of new innovations that are being implemented. The regulator often only supports demonstration projects due to uncertainties of the technological and organizational development of innovations. The lack of regulations for new emerging services shows that a missing or unclear regulatory framework can also have an enabling nature, leading to the possibility for an entrepreneur to develop own rules, until the moment when regulatory mechanisms begin to intervene (Lowe, 1995).

Focusing on the possibilities of autonomous vehicles (AVs) for PT systems in rural areas, Imhof et al. (2020) call for an adaptation of the Swiss regulatory framework towards a flexible PT system where PT currently is being highly subsidized. The case of Singapore and their sandboxing approach examined by Tan & Taeihagh (2021) shows that governing and regulating AV trials with an adaptive strategy that is pre-emptive and responsive at the same time, is a promising way to put the potentials of AVs in value and to minimize their risks for society and the traffic system at the same time. Despite uncertainties of implementing AVs, the Singaporean government was able to ensure stability and adaptability for interested actors to test and implement AVs in the transport system of Singapore.

The Swiss regulatory framework on PT stands in contrast to regulatory frameworks of countries where PT services were deregulated in the past in favor of DRT services. In Great Britain for example, local authorities of rural and dispersed areas filled existing gaps in the PT network with innovative flexible transport modes by deregulating the PT system which then led to independent projects that sometimes overlapped each other or lead to gaps in the provision of PT services, with the consequence of misunderstandings of customers (Brake & Nelson, 2007). New mobility projects that provide flexible transport services with the help of digital applications and that have the characteristics of SIs are scarce in Switzerland. So far, there is not enough evidence, how SIs in the Swiss transport sector deal with regulatory constraints and in which way new spaces of experimentation challenge current regimes.

When analyzing the influence, the regulatory context has on SIs, it is interesting to focus on the emergence and the implementation of SIs. We therefore focus on the evolutionary planning process of a SI and the intersection of the different stages and regulatory aspects. Neumeier (2012, 2017) focused on the planning stages of a SI. His work is based on the literature of governance and participation. Santos et al. (2013) embed the development of SIs in a broader context and develop a life cycle model of SIs. Murray et al. (2010) developed a six stages model, which covers the process from identifying a problem to the stage in which the SI imposes a systemic change. The models have in common that the development of a SI is not considered a linear process. Feedback loops lead to adaptation of preceding stages or that stages can be skipped. Unlike the models by Santos et al. (2013) and Murray et al. (2010), Neumeier's (2012, 2017) model focuses mainly on the creation and planning phase of a SI in rural contexts. Combined with the method of social innovation biographies, introduced in chapter 3.3, Neumeier's (2012, 2017) model allows us a detailed breakdown of the complex planning process into single planning steps. We continue with Neumeier's model, also due to the focus on rural areas that Neumeier (2012, 2017) as well as this paper's research is concentrating on.

The development of a SI starts with a stage of "Problematization" (Neumeier, 2012, 2017). The necessity for societal change is a starting point to form an initial group of actors. The identification and the existence of the impetus for initiating a SI is critical for the constitution of this initial group of actors. Noack and Federwisch (2019) show that an impetus for a rural SI is often originating from external, urban factors and knowledge exchanges. Urban actors bring the necessary knowledge to rural areas to initiate a SI process.

In a second stage of "Expression of interest" (Neumeier, 2012, 2017), the actors' network is changing. New actors join the core group due to their positive view on the planned initiative. In this stage, a SI is reliant on actors that are able to build a community through a diffusion of knowledge on the targeted social issue (Nordberg et al., 2020).

The third stage of planning a SI after Neumeier (2012, 2017) is the stage of "Delineation and coordination". Actors must build common ground on the new form of collaborative action. The innovation here can take new paths as visioned in the beginning. Those actors interested in the innovation begin to negotiate about the new form of action.

The consecutive stage of implementing and testing a SI after Neumeier (2012, 2017) is the tipping point, where success or failure and with it the continuation or stop of the innovation is determined. Neumeier's model ends at this point. SIs that prove to be successful are sustained and multiplicated to have a societal impact for more society members. In the end, a successful SI is subject to a mainstreaming process(Murray et al., 2010; Santos et al., 2013).

3. Case Study and Method

To better understand how a DRT service can be successfully implemented despite regulatory constraints and uncertainties, we focus on a case study of a DRT service in Switzerland. The service is called mybuxi and was implemented in a rural context (in the two communities Herzogenbuchsee and Niederönz) in the northern part of the canton of Bern (see Figure 1). mybuxi is not the first DRT in Switzerland, which is based on a smartphone application as the national operator of rural bus lines tested a DRT service in 2018 and 2019 but did not continue its service afterwards. mybuxi`s regulatory history is unique compared to other DRT services. The latter are typically less flexible and easier applicable to current transport regulations. mybuxi was initiated by a set of private actors distinguishing the service from most DRT services that were established by existing transport enterprises. These typically have extensive knowledge of passenger transport services.

3.1. Regulatory setting

Establishing mybuxi took place in a unique regulatory context and two specific aspects are important to consider: the PT system in Switzerland and the taxi industry. The service design of fully flexible DRT services is situated in between Swiss PT services, which are characterized by line-bound services, and the taxi industry, that provides non-shared individual trips for passengers.

Switzerland has one of the highest rates of PT use in Western Europe (Petersen, 2016) and PT services are offered in remote rural areas when there is a certain amount of population (above 100 people) or when there is a touristic interest. The Swiss PT system is defined in the *Federal Law from 20th March 2009 on the Passenger Transort (Passenger Transport Law, PBG) [Bundesgesetz vom 20. März 2009 über die Personenbeförderung (Personenbeförderungsgesetz, PBG)]*, 2009). The services are divided into four subcategories:

1) **Services of national interest** consist of train services between medium- to large urban centers in Switzerland and in surrounding areas of neighboring countries. The concession to operate long distance traffic services is issued by the Swiss government. Cost-efficient services do not receive financial support from the state.
2) **Services for regional passenger traffic accessing populated areas** are regulated by the Swiss government as well as the respective canton. Populated areas with a population above 100 people need to be accessed by PT. Uncovered costs of the service provision are covered by subsidies provided

by the federal government and the respective canton. Eligible are only services with trains, busses, trams, boats, and cable cars above 8 seats per vehicle. The Federal Office of Transport (FOT) is responsible for issuing concessions for this kind of service.

3) **Services for regional passenger traffic without accessing populated areas** are mostly provided due to touristic reasons. Services, with which no populated area with more than 100 inhabitants is accessed fall into this category. These services are not eligible for subsidies by the Swiss government. Canton and/or municipalities can subsidize these services.
4) **Local services** are those services that provide access to areas inside a municipality and not outside the municipal boundaries. Those services are not eligible for financial support by the Swiss government. The canton and/or municipality can cover uncovered costs.

All service providers offering services in these four categories are obligated to provide their service in the agreement, signed by main Swiss PT actors, of the *Nationaler Direkter Verkehr* (translated *national direct transport*). The agreement stipulates each passenger trip in Switzerland must be under one single contract: one tariff will be defined despite several involved enterprises. PT enterprises are required to cooperate by law. The coordinating alliance “Alliance Swisspass” defines and sets standards for the cooperation (Alliance SwissPass, 2021) and tariffs (Alliance SwissPass, 2020).

Current law acknowledges only line-bound traffic with defined stops. A linked requirement is the publication of a timetable at each stop. The *Federal Act on the Elimination of Discrimination against People with Disabilities* (Disability Discrimination Act) obligates all PT service providers to guarantee access to their service for disabled people. PT vehicles and infrastructures must be accessible for disabled people.

The *Law on the Public Transport of the canton of Bern* (2008) further foresees that the canton can support the planning of PT services by third parties within the scope of PT and traffic coordination (Art. 11, Sec. 1). In the law, the term “third party” remains unclear.

There is a possibility, that the Swiss government issues an exceptional authorization under the PBG, Article 5: “The Federal Council can allow exceptions from the passenger transport shelf” (translated from German). Here, the law does not provide further details on when and how such exceptions can be issued.

The FOT allows research and innovation in its area of responsibility. From their perspective, innovation “means the development of new products, methods, processes and services in industry and society through research” (FOT, 2017, p. 1). Fundable are innovations in the PT system targeting the energy-efficiency of the system to reach the goals of the Swiss energy strategy (SFOE, 2017).

Outside the innovation fund of the FOT, a consortium made up of six Swiss federal offices (energy, health, roads, environment, transport and spatial development) organize the “Office of Coordination for Sustainable Mobility” (in German: Koordinationsstelle für Nachhaltige Mobilität, KOMO) and grant bi-annual funding support for innovative projects with market potential (EnergieSchweiz, online).

The Swiss taxi industry in Switzerland is also facing regulations. Unlike PT services, they are mainly determined by cantonal and municipal regulations. According to the *Decree on Holding and Operating of Taxis (Taxi Decree)*, 2012) of the canton of Bern, operating a taxi service is linked to a permission issued by a municipality. Taxi drivers need to be in possession of a driver license that allows for-profit transport of passengers. A municipality can determine tariffs for a taxi and if necessary, could subsidize the service. A taxi trip is determined as a transport service for a single guest or a small group of guests that book a ride from A to B.

3.2. Spatial setting

The municipalities of Herzogenbuchsee and Niederönz are situated in the north of the canton of Bern, Niederönz bordering to the canton of Solothurn. Both are classified as rural center-villages (FSO, 2017). Herzogenbuchsee has a population of 7'200 inhabitants and Niederönz of 1'670 inhabitants in the year 2018 (FSO, 2020).

The central train station, situated in Herzogenbuchsee, is the backbone of the local. Direct trips to the capital of Bern take 34 minutes and to Zurich 53 minutes. Departing from the train station, several bus lines serve surrounding villages. Those bus lines access bus stops along the main traffic axis inside Herzogenbuchsee and Niederönz but only operate to each half or full hour. The bus lines generally do not access points of interests like a retirement home in the western as well as public sport facilities (see Figure 1).

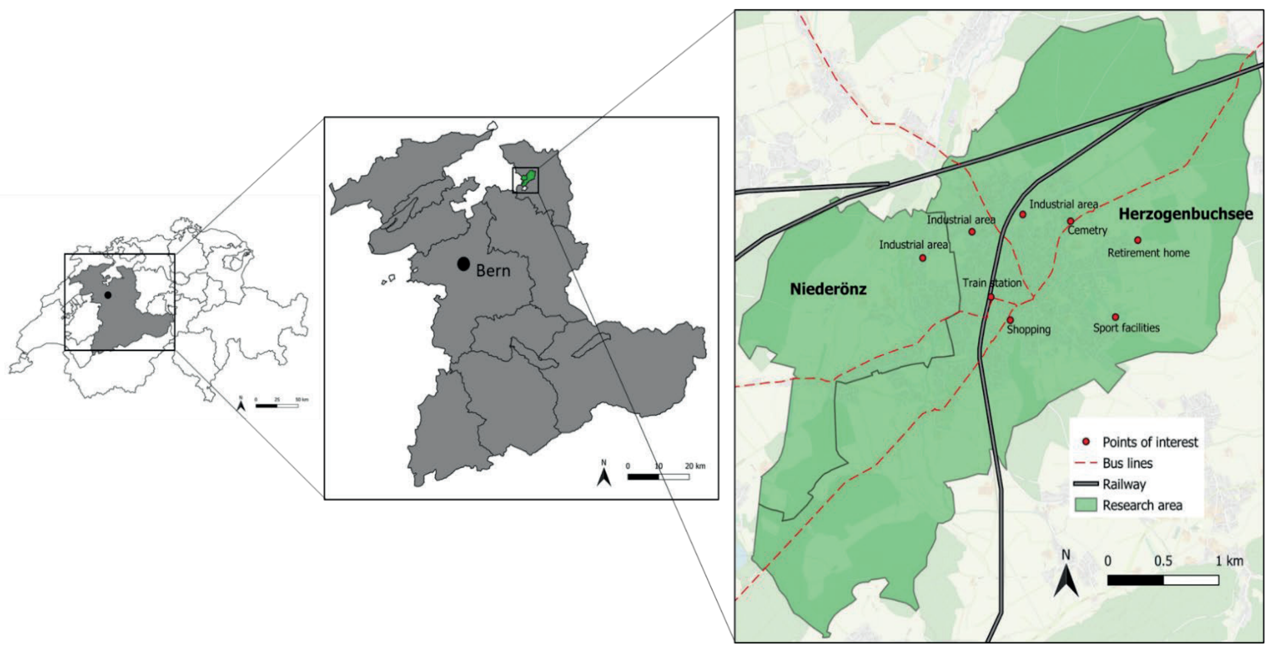

Figure 1 Geographical situation of mybuxi in Switzerland (left) and the canton of Bern (middle); local situation (right)

Mybuxi started to provide the services both municipalities in 2019. After the first year, it had a high acceptance rate. The service is based on a smartphone application allowing the request of a ridesharing service at any time during operating hours. The service ensures a service between the first and the last train from and to Herzogenbuchsee. On Fridays and Saturdays, the service is ensured until 01:40 o'clock and on weekdays until 00:40 o'clock at night. Trips are possible from and to all points reachable by car inside the municipalities' boundaries. A single trip did cost 3 Swiss Franc (CHF) during the first year of operation and then was raised to 4 CHF. Two electric mini-van (Nissan E-Valia) are used for the transport of the passengers. Volunteer drivers earn 10 CHF per hour and take over one shift every second week. The service is locally managed by a specially founded association called EBuxi. The start-up mybuxi supports the EBuxi association in decisions on the daily business and provides the technological infrastructure.

3.3. Methodological approach

SIs like mybuxi are embedded in a broader context and local conditions play a crucial role (Deserti & Rizzo, 2020). The process of developing and implementing a SI is considered non-linear, calling for a method that can picture the entire innovation process (Kleverbeck & Terstriep, 2017). To better understand the regulatory issues that arise during the innovation process from the ideation to operations, we utilized the method of social innovation biographies (SBI) (Butzin & Widmaier, 2016; Kleverbeck & Terstriep, 2017). SBIs help us to identify the crucial planning steps of the SI of mybuxi. Additionally, the method of SBIs provides a guideline for researchers to deal with the high complexity of SIs and the involved actors. The methodological approach of SIB is a combination of analytical and process steps. Process steps are the narrative and semi-structured interviews as well as the last steps of building the SIB; analytical steps are the egocentric network analysis and the triangulation.

The method involves the following steps:

We selected mybuxi as the subject for the SBI because of the project's focus on improving the local PT for the population. Additionally, the actor composition (especially civil actors of the EBuxi association as well as the mybuxi start-up) and planning process of mybuxi is typical for a SI. To better understand the conditions how the innovation developed in the planning process evolved in detail, we first conducted an in-depth desk research to identify crucial interview questions.

Following the case selection, one narrative interview helped us to identify key factors in the history of the innovation process. Through this interview, we gained insights as to the background of the idea, involved actors and milestones in the innovation process. We conducted this interview in March 2020 with the founder of mybuxi (see Table 1). This interview allowed us to identify initial ideas about regulatory constraints and uncertainties. These ideas were then part of the interviews that followed (e.g. interviews with authorities at different government levels).

With the help of the first narrative interview and the desk research, we identified actors involved in the innovation. We mapped these actors in a network analysis and documented them in a narrative description.

Semi-structured interviews: The key actors that were identified in the initial narrative interview and through the egocentric network analysis were identified. We followed up with them with semi-structured interviews. A total of ten interviews with actors involved in the innovation process were conducted. To cover all types of actors, we interviewed members of the EBuxi association, an associate of mybuxi, local, cantonal, and state authorities, a representative of the software provider, a planner of a local transport enterprise as well as a representative of one of the main sponsors of mybuxi. The interviews took between ½ and 1½ hours and were conducted by telephone due to COVID-19 restrictions. All interviews were conducted between April and May 2020 and were transcribed with the F5 software.

Table 1 Interview description

Function	Business	Level	Duration (in min)
Member of steering committee	EBuxi	Local	83
Member of steering committee	EBuxi		82

Mayor	Municipality of Herzogenbuchsee		60
Founder	mybuxi	Regional	87
Offer planner	Regional bus and train operator		44
Scientific researchers (Traffic coordination & Offers and infrastructure)	Office of public transport; Canton of Bern		76
Mobility intrapreneur & project leader	National train operator & mybuxi	National & local	33
Deputy leader	Volunteer development fund	National	71
Co-department chef with scientific researcher	Federal office of transport		68
Project leader; president working group mobility 4.0	Federal roads office		63
Account manager	Software provider	International	72

Triangulation: Based on the egocentric network analysis and the semi-structured interviews, we applied the framework of Neumeier (2012, 2017) on the planning process of our SI. This framework helped to identify necessary planning steps in each stage of the SI. On base of these stages, we can illustrate the process of mybuxi till implementation. In this step, we enriched the data with documents of the federal and cantonal law.

Building the SBI: The last step consisted of writing and analyzing the entire innovation process and to create a complete SBI. The narrative was structured in different sections such as the planning steps that were involved in the creation of mybuxi, questions related to the regulatory framework, descriptions of details according to the three innovation stages after Neumeier (2012, 2017).

4. Results: The process of planning the SI of mybuxi

The following sections highlight the involved actors, the important planning steps and the regulatory questions relating to each planning stage. All results are summarized in Table 2.

4.1. Problematization

Planning the mybuxi service started in early 2018 with two parallel ideation processes that involved local actors in Herzogenbuchsee, and actors engaged in a meetup in the Swiss capital city of Bern. All ideas developed in this stage were based on the ambition to challenge the rather high car dependency and to compensate the lack of attractive PT services in rural areas.

At the local level, a handful key members of the community (authorities and civil society) were involved in the ideation process. They identified the need for a local transport service accessing all populated areas in the local community. While the local PT service only provided stops along selected axis and this was perceived as limiting, the actors had the idea to provide a flexible and sustainable transport service through a DRT solution. Additionally, the actors also identified the lack of a taxi service in their municipality. Based on the knowledge of technological solutions, the local actors began to look for suitable partners to implement such a DRT service.

While the idea for a local DRT was established at the local level, other efforts with similar ambitions to challenge current mobility regimes and to contribute to a transition process towards sustainable rural mobility took place nearby. A Bern based innovation meetup called "innolab smart mobility" attracted actors of PT enterprises, IT development, start-ups, and consulting enterprises. The participants of the meetup discussed why Swiss PT was still mainly focused on the supply-side when technologies for DRT transport have been available and were already in use in other countries. The meet-up actors noticed that DRT traffic could improve transport services in rural areas, emphasizing that DRT would trigger a service improvement where PT does not provide access to all inhabitants in a satisfying quality. Upon several meetings, one member of the meetup founded the start-up mybuxi in 2018. The start-up was successful in applying for public research grants from KOMO, a national research fund on sustainable mobility administered by six federal offices. First contacts to these six federal offices took place to discuss the proposed research project, helping to define the main goals of the project. Two main goals were set to evaluate how local DRT services challenge current socio-technical regimes:

- Evaluation of saving potentials if cost-inefficient PT services are replaced by DRT services
- Estimation of the potential modal shift from private transport modes to a DRT service

No further actors were involved in the problematization stage. The ideation processes of the local actors and the newly founded start-up mybuxi did not merge so far.

At this early stage, it remained rather vague how SI could be governed and whether the idea of mybuxi would fit in existing (local and national) regulatory frameworks or not. Two possible regimes and their corresponding regulatory framework were identified to be theoretically suitable for a local DRT service: the local PT and the taxi regime. As the ideation process of the local actors was so far restricted to a desire of improving local accessibility, there were no debates about the regulatory framework.

For the mybuxi start-up, however, the regulatory questions were important. In their view, the existing taxi law seemed to be unsuitable for a DRT service in rural areas. The reason lies in the simplistic understanding of a taxi ride as a trip from A to B. This would not have been in the sense of DRT service that tries to pool as many trip demands with similar trip targets as possible. The higher a pooling rate, the better the ecological impact of the service and as a result revenues per vehicle kilometer increase. Based on this view, the taxi regime was not further considered as suitable regime and regulatory framework. Based on the assumption that mybuxi would be more suitable as PT service than a taxi service, the following questions concentrated on the regulations of the PT regime. But at this stage of the SI, no clear decisions on how to regulate a local DRT service based on the regulatory framework of the PT regime were made.

In this stage of the SI, the initial set up of the SI was driven by the ambitions of the local actors to solve the local PT problems. With the goal to provide a local DRT service, the local actors tackled the challenge to improve the local PT quality in favor of those people without direct access to an own car. This supports Pol and Ville's (2009) view that SIs are primarily developed with the goal to have a positive impact on local quality of life. Tschumi et al. (2020) argue that SIs are increasingly seen as a possible driver of development in rural areas and this was also confirmed through our interviews as the founder of mybuxi highlighted that the DRT service should also provide a reliable, safe service with a positive image for these rural areas.

The initial planning steps involved the positioning of a novel idea of DRT within the existing socio-technical environment (see Geels, 2004; Hodson et al., 2017). All involved actors aimed for a transition towards a more sustainable local transport service in a rural setting. The discussions during this first stage were dominated by the idea of a DRT service that would co-exist with the current PT regime as the involved actors did not want to limit already scarce PT services.

While new PT services in Switzerland are developed based on data-based indicators like population density and size and are governed on national, cantonal, or local levels, a completely new arrangement of actors started to emerge in the case of mybuxi. Especially the founding of a start-up for the purpose of providing a DRT service is considered a novelty in Switzerland. From the beginning, the startup mybuxi represented a competing governance approach to traditional PT services as it started to challenge the monopoly of mainstream transport service providers in rural areas.

4.2. Expression of Interest

In the second stage of the SI (Expression of Interest Stage), the ambitions of the local actors and those of the actors involved with the startup mybuxi merged thanks to a spontaneous meeting with a high-ranking official of the FOT. To secure a successful operational business, the so far strongly involved actors of the public administration of the municipality officially left the project. The ambitions of the remaining actors to challenge and reconfigure the rural sustainable transport system became clearer in this stage.

First, the project gained big momentum after a contact between the local actors and a high-ranking federal official of the Federal Office of Spatial Development at a national mobility congress in the middle of 2018. The federal official knew that the mybuxi start-up was searching for suitable pilot regions within the scope of the KOMO research project. Up to now the so-far separate objectives and ambitions of the local actors and the mybuxi startup merged. Both involved municipalities ensured public subsidies for the experimentation phase of the project. To attract new partners and to plan the operational business, a local association called EBuxi was founded in November 2018. The mybuxi start-up ensured strategical support and was involved in certain operational planning steps.

In this second stage, regulatory questions remained in the background and did not dominate because no decisions were made so far about which exact regulations the service had to follow, leaving all actors in an unclear situation. Despite the withdrawal of the local authority actors (see chapter 6.2.1), these actors ensured political support and a regulatory framework as far as their political authority reached. Additionally, the mybuxi start-up successfully got a permission by the Office for PT of the canton of Bern to experiment with DRT services in form of three pilot projects. This is seen by the interview partners as a generous interpretation of the cantonal law, as the canton's interest in the findings regarding the financial, traffic-related, and social impact of the project is high. The granted money from the canton of Bern was bound to the planning of the project and not to the operational business. Current developments of the technological environment are further important factors why the project gets supported by the canton. The actors of the canton were especially interested in gaining more knowledge about how to deal with those new possibilities and how they contribute to a more sustainable transport system.

In this second stage of the SI, no changes in the configurations of the socio-technical environment were identified. The overarching goals of the SI in this stage rested on the ambitions to provide an attractive, sustainable local transport service.

The merging pathways of the local actors and the newly founded mybuxi start-up go along with the findings of Noack and Federwisch (2019) that SIs in rural areas often rely on urban impulses. In our case, the involvement of the mybuxi start-up was especially crucial for designing the final services. The knowledge and network of the mybuxi founder complemented the existing local knowledge and network.

With the withdrawal of the municipality, there have been adaptations of the governance arrangement of the project itself. Even though the municipality was no longer involved, the local public sector retained an important supportive role (Butzin et al., 2017). Several interview partners highlighted the enabling role of the municipality for the entire mybuxi project. Yet, compared to governing a classical PT regime in a municipality, the governance arrangement at this stage remained fragmented in the sense that the SI challenged established PT laws and regulations. The governance approach of the cantonal authorities suggests a co-existence of the SI with other PT services as the issued permit for the pilot projects of mybuxi was based on the existing laws.

4.3. Delineation & Coordination

In the final planning stage, determining the regulatory framework under which the services mybuxi would have been able to operate was the dominant and most crucial topic. The inclusion of external knowledge in form of a specialized lawyer was critical for the successful implementation of the SI.

There were several operational tasks to solve in this third step of planning the SI. At the local level, the previously newly founded EBuxi association had to find sponsors to finance the operation. This is related to the fact, that so far, there was no clear regulatory framework identified in the two preceding stages of planning that would have guarantee public subsidies. With the help of an innovation fund of the local energy provider, a vehicle was financed. Additionally, the association had to engage several volunteer drivers for the daily business. In addition, the mybuxi start-up collaborated with a Spanish software enterprise that provides the suitable software for DRT services in rural areas. All drivers and the EBuxi steering committee got introduced to the software. The operational planning process so far was ready for the final implementation of the mybuxi service.

Answering crucial questions regarding the regulatory framework was quite challenging in this stage. The actors involved in the mybuxi startup set themselves rather high goals to become part of the mainstream PT system. Being part of the PT system would have meant that mybuxi could continue its services over the duration of the granted pilot project of mybuxi (see problematization stage) and would have allowed the service for subsidies by the FOT and the canton of Bern. In this and the previous stages, the mybuxi start-up was mainly responsible for dealing with all questions related to the regulatory context; the local actors of the EBuxi association did not have to deal with this type of questions.

In a first attempt, the mybuxi start-up tried to solve the open regulatory questions with the Federal Office of Transport (FOT). Ambivalent, contradicting positions inside the FOT became obvious. The efforts of mybuxi to improve the rural mobility system was positively perceived by persons in charge of the political and strategical development of the Swiss mobility system. From their perspective, mybuxi was the opportunity to test new DRT services in rural areas in Switzerland. Another point of view was then indicated by persons of the FOT responsible for the concession of PT services. They proposed to proceed in similar ways as other PT services with a concession form. Filling out this form highlighted the differences between mybuxi`s DRT service as a niche offering and the classical PT services. Compared to traditional PT services, a hindrance for on-demand services is the definition of prices related to trip distances. This in turn is based on a sector-wide agreement to offer one PT ticket per trip, despite different PT providers. As pooled rides get longer, this tariff definition is not suitable for mybuxi. Further, operating with virtual stations is a challenge for barrier-free access to the vehicles. Fulfilling all regulations of the Disability Discrimination Act would have had huge implications for the interior design of the vehicles and the economic efficiency of the service. Based on these and several other regulatory constraints, the concession was not assigned to mybuxi.

At this point, mybuxi involved an external specialized lawyer on PT regulations. With his help, the possibilities to position mybuxi inside the current regulatory framework were evaluated. A possibility was elaborated that the provision of the service would take place with an exceptional authorization under the PBG, the law on Swiss PT. In agreement with a lawyer of the FOT, an exceptional authorization was issued. The mybuxi service was allowed to provide its services beyond the permission related to the KOMO project. This authorization is rarely used as the mybuxi start-up founder mentioned in the interview. It allowed to experiment with the possibilities of a rural DRT service. Yet, the permission obliged mybuxi to fully report findings from the operational business to the FOT and other Federal offices interested in the results. One of the main reasons why mybuxi obtained the authorization, was the high interest of the federal and cantonal government to gain more knowledge about on-demand solutions in areas where current PT is cost-inefficient. At the time of our research, mybuxi remains ineligible for federal subsidies despite the exceptional permission. One of the success factors relates to the degree of trust of the actors in each other (particularly local and federal actors) given that a start-up obtains the opportunity to experiment with a new approach despite regulatory uncertainties. On the other hand, the actors involved in the startup mybuxi trusted public officials that all provided information would have been handled in a confidential manner.

The third planning stage of delineation and coordination seemed to have been crucial in terms of the SI fitting into the traditional regulatory framework. The exceptional operating permission that was issued for a longer period than expected, ensured the actors with a certain degree of planning security. But at the same time, the goal to be acknowledged as PT service was missed and this has – in the views of the interviewees – economic consequences for the service. As a result, the costs of the mybuxi service that remain uncovered will need to be financed by private sponsors in the future. Interviewees acknowledged that knowing that providing the mybuxi service is linked to remaining regulatory uncertainties makes the search for sponsors rather difficult. This supports the findings of Hubert (2011) and Grimm et al. (2013) who identified the negative influence of an incompatible regulatory environment on SIs.

Our data for this stage also shows that there is a certain need of external knowledge in the planning of a SI when dealing with regulatory uncertainties. The involvement of an external lawyer was crucial for obtaining an exceptional permission outside the PT regulations. Nordberg et al. (2020) show that external knowledge is necessary to deal with regulatory uncertainties and constraints. Our case illustrates this point nicely.

Regarding the future of SIs and their ability to transform service provision in rural areas, the founder of mybuxi noted that Switzerland does not provide a good environment for experimenting SIs. This may impact how new forms of mobility are regulated in the future. Currently only experimental cases like mybuxi, that were able to persuade the regulatory agencies in their favor, can operate outside an existing regulatory framework (Lo Schiavo et al., 2013). Regulations are then based on the expertise generated in the pilot projects. From the perspective of the mybuxi start-up the Swiss approach contrasts, for example, with Asian countries where new technologies are tested based on a loose regulatory framework. There, regulations are an answer to the social and systemic development of a technology (Tan & Taeihagh, 2021). Nevertheless, it seems that the missing experimental approach is counteracted by the openness of the responsible Swiss federal office to discuss regulatory constraints and that agreements can be arranged bilaterally without unreachable hurdles for new enterprises like mybuxi.

There are no clear signs at this point, how the final mybuxi service will be integrated in the socio-technical environment of the PT provision in rural areas. The conflicting understandings inside the FOT shows conflicting understandings on the governance of mybuxi (Hodson et al., 2017). By trying to prevent the PT system from changing, lawyers inside the FOT try to protect the regulatory framework from radical changes. The rigid regulatory framework of the PT regime is – from the perspective of the FOT – a way to protect the PT system and to secure quality in services (Rodrigue, 2020). We also see that the responsible persons for strategic and political decisions inside the FOT are open to finding suitable ways to create room for experiments. This supports the view of Ongkittikul and Geerlings' (2006) that regulatory reforms are a suitable way to improve the PT quality.

	Problematization	**Expression of Interest**	**Delineation & Coordination**
Actors & planning steps	Local key actors plan DRT service to improve local PT system Urban meetup actors develop research project for rural DRT services Foundation of mybuxi start-up	Merging pathways of local actors & mybuxi start-up thanks to high ranking federal official Local municipalities ensure public subsidies Founding EBuxi association Mybuxi start-up ensures strategical and where necessary operational support Canton of Bern issues a permission to operate	Operational tasks of the local actors (and mybuxi start-up in certain steps): - Sponsoring - Finding volunteer drivers - Introduction to the DRT software An external lawyer helps to deal with regulatory challenges
Regulatory questions	Identification of two possible regulatory frameworks: PT and taxi regime Mybuxi start-up identifies the PT regulations as favorable. Taxi regime seems not suitable.	Municipalities withdraw from the planning process, ensuring political support Permission by the canton of Bern is related to a high interest in the project's findings; but the mybuxi service is not acknowledged as PT service	Ambitions of mybuxi start-up to be acknowledged as PT service Bilateral meetings with FOT and mybuxi start-up. Ambivalent, contradicting positions inside FOT Unsuccessful concession process Success in obtaining exceptional permission
Conclusions	Developing DRT service to improve local PT system (Pol & Ville, 2009) Idea of rural DRT service may contribute to positive regional development (Tschumi et al., 2020) Positioning idea of rural DRT service inside the existing socio-technical environment (Geels, 2004; Hodson et al. 2017) Identification of a new governance arrangement regarding PT (-similar) services	Merging pathways of local and start-up actors show that urban impulses are crucial for Sis in rural areas (Noack & Federwisch, 2019) Crucial role of the local public sector for SI (Butzin et al., 2017) No configurations of the socio-technical environment (Hodson et al. 2017) Governance arrangement contradicts on the local level of governing a PT service; on the cantonal level, a rather co-existent situation (Hodson et al., 2017)	Incompatible regulatory framework hinders mybuxi service to ensure long-lasting service (Hubert, 2011; Grimm et al. 2013) External knowledge to deal with regulatory uncertainties (Nordberg et al. 2020) Missing sandboxing approach considered as hindrance (Lo Schiavo et al., 2013; Tan & Taeihagh, 2021) No indications of changes in socio-technical environment FOT: conflicting understandings on governing mybuxi service (Hodson et al., 2017)

Table 2 Summary of planning the SI of mybuxi

5. Conclusion

The aim of this paper is to show how the SI of mybuxi contributes to a transition towards a more sustainable transport environment in rural areas. Answering this question was in our case study only possible by including the discussions on the regulatory framework and how regulatory questions affected the planning process of the mybuxi service. To answer the research questions, we used the methodological approach of SBIs and totally conducted 11 interviews with important actors of the SI of mybuxi.

Based on the SBI of the mybuxi service, we illustrate that the development of the DRT service in a rural setting can be well examined along the planning stages of a SI introduced by Neumeier (2012, 2017). The actors' goal to improve the local transport system in the involved municipalities were achieved by introducing an attractive DRT service. This was only possible through solving regulatory questions in the final planning stage. The successful planning of the mybuxi service may contribute to a transition towards a more sustainable rural transport environment, as the SI ensures an increase in the accessibility of all settlement areas in the municipalities. Unlike in urban areas, experiments in rural areas like the mybuxi SI are isolated niches challenging dominant regimes. Despite its isolated emergence, mybuxi will contribute over time to a sustainability transition process (Geels, 2005; Hodson et al., 2017). The improvement in PT access means especially for the targeted user group of people without access an improvement in their access to sustainable transport modes. We consider this planning process of the mybuxi service as one possible way to successfully implement a SI in rural areas.

Additionally, the paper details how complex regulations in the PT regime influence the planning process of a SI in this realm. In the first two stages, hardly any question emerged regarding the regulation of the service. Yet, in the final planning stage when coordination and delineation of the SI were critical and the SI was already defined, the regulatory questions became crucial. Like in Grimm et al. (2013), the federal actors responsible for regulating the service tried to shield the current regulatory framework from disruptive change. Involving external knowledge (Nordberg et al., 2020) was helpful as the obtained exceptional permission allowed a continuation of the service (Grimm et al., 2013; Hubert, 2011). Further case-specific examinations in which way and with which consequences a rigid regulatory framework hinders the process of SI in rural transport systems are needed.

This research is limited to one specific SI in a rural area, and we specifically focused on the planning stages. There is a need to better understand how DRT services in rural areas can further emerge in favor of a sustainable rural transport environment. A special focus must remain on the regulatory framework: changes here can have significant implications on the service design of DRT service in rural areas. A better understanding of the relations between DRT services, SIs and the regulatory framework will help to better prepare all involved actors for the emergence of new mobility forms like for example autonomous vehicles in rural areas.

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STATUTORY DECLARATION

"I declare herewith that this thesis is my own work and that I have not used any sources other than those stated. I have indicated the adoption of quotations as well as thoughts taken from other authors as such in the thesis. I am aware that the Senate pursuant to Article 36 paragraph 1 litera r of the University Act of September 5th, 1996 and Article 69 of the University Statute of June 7th, 2011 is authorized to revoke the doctoral degree awarded on the basis of this thesis.

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